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Miss M M Howe

A SYSTEM
OF
NATURAL PHILOSOPHY;

IN WHICH

53239

THE PRINCIPLES OF MECHANICS,
HYDROSTATICS, HYDRAULICS, PNEUMATICS, ACOUSTICS, OPTICS, ASTRONOMY, ELECTRICITY, AND MAGNETISM,
ARE
FAMILIARLY EXPLAINED,
AND
ILLUSTRATED BY MORE THAN TWO HUNDRED ENGRAVINGS.

TO WHICH ARE ADDED,
QUESTIONS FOR THE EXAMINATION OF THE PUPILS
DESIGNED
FOR THE USE OF SCHOOLS AND ACADEMIES.

THIRTEENTH EDITION.

BY J. L. COMSTOCK, M. D.
Mem. Con. M. S.; Hon. Mem. R. I. M. S.; Author of Notes to Conv. on Chemistry; Auth. of Gram.-Chem.; of Elem. Mineralogy; of Nat. Hist. of Quadr. and Birds, &c.

Hartford:

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STEREOTYPED BY JAMES CONNER, NEW-YORK.

1834.

DISTRICT OF CONNECTICUT, ss.

BE IT REMEMBERED, That on the twenty-fourth day of May, in the fifty-fifth year of the Independence of the United States of America, J. L. COMSTOCK, of the said District, hath deposited in this office the title of a Book, the right whereof he claims as author and proprietor, in the words following, to wit; "A System of Natural Philosophy; in which the principles of Mechanics, Hydrostatics, Hydraulics, Pneumatics, Acoustics, Optics, Astronomy, Electricity, and Magnetism, are familiarly explained, and illustrated by more than two hundred engravings. To which are added, Questions for the examination of the Pupils. Designed for the use of Schools and Academies. By J. L. Comstock, M. D.; Mem. Con. Med. Soc.; Hon. Mem. R. I. M. S.; Author of Notes to Conv. on Chem.; Author of Gram. Chem.; of Elem. Mineralogy; of Nat. Hist. of Quadr. and Birds, &c." In conformity to the act of Congress of the United States, entitled, "an act for the encouragement of learning, by securing the copies of Maps, Charts, and Books, to the authors and proprietors of such copies, during the times therein mentioned."—And also to the act, entitled, "an act supplementary to an act, entitled, 'an act for the encouragement of learning, by securing the copies of Maps, Charts, and Books, to the authors and proprietors of such copies, during the times therein mentioned,' and extending the benefits thereof to the arts of designing, engraving, and etching historical and other prints."

CHARLES A. INGERSOLL, *Clk. of the Dis. of Connecticut.*

A true copy of Record, examined and sealed by me,

CHARLES A. INGERSOLL, *Clk. of the Dis. of Connecticut.*

PREFACE.

WHILE we have recent and improved systems of Geography, of Arithmetic, and of Grammar, in ample variety,—and Reading and Spelling Books in corresponding abundance, many of which show our advancement in the science of education, no one has offered to the public, for the use of our schools, any new or improved system of Natural Philosophy. And yet this is a branch of education very extensively studied at the present time, and probably would be much more so, were some of its parts so explained and illustrated as to make them more easily understood.

The author therefore undertook the following work at the suggestion of several eminent teachers, who for years have regretted the want of a book on this subject, more familiar in its explanations, and more ample in its details, than any now in common use.

The Conversations on Natural Philosophy, a foreign work now extensively used in schools, though beautifully written, and often highly interesting, is, on the whole, considered by most instructors as exceedingly deficient— particularly in wanting such a method in its explanations, as to convey to the mind of the pupil precise and definite ideas; and also in the omission of many subjects, in themselves most useful to the student, and at the same time most easily taught.

It is also doubted by many instructors, whether Conversations is the best form for a book of instruction, and particularly on the several subjects embraced in a system of Natural Philosophy. Indeed, those who have had most experience as teachers, are decidedly of the opinion that it is not; and hence we learn, that in those parts of Europe where the subject of education has received the most attention, and consequently where the best methods of conveying instruction are supposed to have been adopted, school books in the form of conversations are at present entirely out of use.

The author of the following system hopes to have illustrated and explained most subjects treated of, in a manner so familiar as to be understood by the pupil, without requiring additional diagrams, or new modes of explanations from the teacher.

Every one who has attempted to make himself master of a difficult proposition by means of diagrams, knows that the great number of letters of reference with which they are sometimes loaded, is often the most perplexing part of the subject, and particularly when one figure is made to answer several purposes, and is placed at a distance from the explanation. To avoid this difficulty, the author has introduced additional figures to illustrate the different parts of the subject, instead of referring back to former ones, so that the student is never perplexed with many letters on any one figure. The figures are also placed under the eye, and in immediate connexion with their descriptions, so that the letters of reference in the text, and those on the diagrams, can be seen at the same time. In respect to the language employed, it has been the chief object of the author to make himself understood by those who know nothing of mathematics, and who indeed had no previous knowledge of Natural Philosophy. Terms of science have therefore been as much as possible avoided, and when used, are explained in connexion with the subjects to which they belong, and it is hoped, to the comprehension of common readers. This method was thought preferable to that of adding a Glossary of scientific terms.

The author has also endeavored to illustrate the subjects as much as possible by means of common occurrences, or common things, and in this manner to bring philosophical truths as much as practicable within ordinary acquirements. It is hoped, therefore, that the practical mechanic may take some useful hints concerning his business, from several parts of the work.

Hartford, May, 1830.

RECOMMENDATIONS.

The attention of Teachers, and other gentlemen interested in education, is requested, to the following notices of this "System of Philosophy," which are from the most respectable sources:

From John Griscom, LL. D. Principal of the New-York High School.

New-York, June 19th, 1830.

ESTEEMED FRIEND,

I have received and examined thy book on Natural Philosophy, with much satisfaction; I have no hesitation in saying, that I consider it better adapted to the purposes of School Instruction, than any of the Manuals hitherto in use with which I am acquainted. The amiable author of the Conversations threw a charm over the different subjects which she has treated of, by the interlocutory style which she adopted, and thus rendered the private study of those Sciences more attractive; but this style or manner, being necessarily diffuse, is not so well adapted to the didactic forms of instruction pursued in Schools. Hence also, more matter can be introduced within the same compass, and I find, on comparing thy volume with either of the editions of the Conversations now in use, that the former is much better entitled to the appellation of a System of Natural Philosophy, than the latter. The addition also of Electricity and Magnetism, is by no means unimportant in a course of instruction in the Physical Sciences.

I am, with great respect, JOHN GRISCOM.

P. S. I have recommended thy book to all the pupils of our High School, who attend to Natural Philosophy, and it is the only Book which we shall now use as a Class Book.

From H. Potter, Professor of Mathematics and Natural Philosophy, in Washington College, Hartford, Conn.

DEAR SIR,

I have examined a portion of your work on Natural Philosophy, and am happy to say that I am, in general, well pleased with the plan you have adopted. With the exception of a few errors, which will doubtless be corrected in a subsequent edition, your mode of treating your subjects seems to be sufficiently scientific for a work so very elementary in its character—and at the same time, it is so popular, as to present few difficulties to an uneducated person of ordinary understanding. The diagrams are generally well drawn, and the plan of introducing them on the same page with the explanation, will contribute greatly to the comfort and advantage of your readers.

Very truly Yours, H. POTTER.

DR. J. L. COMSTOCK.

Washington College, July 1, 1830.

From the Right Rev. T. C. Brownell, D. D., LL. D., President of Washington College.

From a cursory examination of the work, I willingly concur in the above recommendation. I know of no similar Book, which, for plan and arrangement, is so well calculated for the use of Schools. T. C. BROWNELL.

DR. J. L. COMSTOCK.

DR. COMSTOCK,

I have examined your Treatise on Natural Philosophy with considerable attention, having used it as a Text Book in the Grammar School, immediately on its publication. With this knowledge of its contents, I have no hesitation in pronouncing it the best work on this subject, for the use of Schools and Academies, with which I am acquainted, and therefore hope to see it extensively introduced.

E. P. BARROWS,
Principal Hartford Grammar School

Hartford, June 26, 1830.

DR. COMSTOCK,

Dear Sir,—I have carefully examined your System of Natural Philosophy, and am of opinion that it is far superior to any work of the kind now in use. As particular excellencies of this System, I would mention its happy illustrations—the perspicuity, variety, arrangement, and originality of its diagrams, and the addition of much new, interesting, and useful matter. It appears, indeed, to have been a principal object with you, to give the Student *correct* and *definite* ideas, and in this attempt I think you have been peculiarly successful. I have been highly pleased with the work myself, and can heartily recommend it to the attention and patronage of the public.

OLIVER HOPSON,
Principal of the Select School.

Hartford, June 1, 1830.

From the Teacher of Mathematics and Natural Philosophy in the High School, at Ellington, Conn.

Dear Sir,—I have examined your "System of Natural Philosophy," and used it as a text-book for one class. I consider it better adapted to the purposes of elementary instruction than any work of a similar kind with which I am at present acquainted.

ZEBULON CROCKER.

Ellington School, Aug. 10, 1830.

GENTLEMEN,

I have examined "Comstock's Natural Philosophy," and think it is a book excellently adapted to communicate a competent knowledge of the various subjects on which it treats. It does not enter into that depth of Scientifical and Mathematical illustration, of which the subjects are susceptible; but it illustrates, in a familiar way, most of the principles of Natural Philosophy, and is enriched with a statement of practical details in that science. It is a book well calculated to be highly useful in our Schools and Academies.

Most respectfully Yours, &c. ROBERT BRUCE,
President of Western University, Penn.

GENTLEMEN,

I have examined many of those Treatises of Natural Philosophy that have been prepared for the younger classes of Students—Dr. Comstock approaches more nearly to the idea I have formed of what such a work should be, than any I have met with. It is rich in Philosophical facts, its explanations are popular, its illustrations practical, and its language perspicuous. It is perfectly adapted to those students at school that do not take an extensive course of Mathematics, and to those that do, it will serve the important purpose of an Introduction.

Yours, respectfully, J. H. FIELDING,
President of Madison College.

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NATURAL PHILOSOPHY.

THE PROPERTIES OF BODIES.

A **Body** is any substance of which we can gain a knowledge by our senses. Hence air, water, and earth, in all their modifications, are called bodies.

There are certain properties which are common to all bodies. These are called the essential properties of bodies. They are *Impenetrability*, *Extension*, *Figure*, *Divisibility*, *Inertia*, and *Attraction*.

Impenetrability.—By impenetrability, it is meant that two bodies cannot occupy the same space at the same time, or, that the ultimate particles of matter cannot be penetrated. Thus, if a vessel be exactly filled with water, and a stone, or any other substance heavier than water, be dropped into it, a quantity of water will overflow, just equal to the size of the heavy body. This shows that the stone only separates or displaces the particles of water, and therefore that the two substances cannot exist in the same place at the same time. If a glass tube open at the bottom, and closed with the thumb at the top, be pressed down into a vessel of water, the liquid will not rise up and fill the tube, because the air already in the tube resists it; but if the thumb be removed, so that the air can pass out, the water will instantly rise as high on the inside of the tube as it is on the outside. This shows that the air is impenetrable to the water.

What is a body? Mention several bodies. What are the essential properties of bodies? What is meant by *impenetrability?* How is it proved that air and water are impenetrable?

If a nail be driven into a board, in common language, it is said to penetrate the wood, but in the language of philosophy, it only *separates*, or *displaces* the particles of the wood. The same is the case, if the nail be driven into a piece of lead; the particles of the lead are separated from each other, and crowded together, to make room for the harder body, but the particles themselves are by no means penetrated by the nail.

When a piece of gold is dissolved in an acid, the particles of the metal are divided, or separated from each other, and diffused in the fluid, but the particles of gold are supposed still to be entire, for if the acid be removed, we obtain the gold again in its solid form, just as though its particles had never been separated.

Extension.—Every body, however small, must have length, breadth, and thickness, since no substance can exist without them. By extension, therefore, is only meant these qualities. Extension has no respect to the size, or shape of a body. The size and shape of a block of wood a foot square is quite different from that of a walking stick. But they both equally possess length, breadth, and thickness, since the stick might be cut into little blocks, exactly resembling in shape the large one. And these little cubes might again be divided until they were only the hundredth part of an inch in diameter, and still it is obvious, that they would possess length, breadth, and thickness, for they could yet be seen, felt, and measured. But suppose each of these little blocks to be again divided a thousand times, it is true we could not measure them, but still they would possess the quality of extension, as really as they did before division, the only difference being in respect to dimensions.

Figure, or *form*, is the result of extension, for we cannot conceive that a body has length and breadth, without its also having some kind of figure, however irregular.

Some solid bodies have certain or determinate forms, which are produced by nature, and are always the same, wherever they are found. Thus a crystal of quartz has six sides, while a garnet has twelve sides, these numbers being

---

When a nail is driven into a board or piece of lead, are the particles of these bodies penetrated or separated? Are the particles of gold dissolved, or only separated by the acid? What is meant by extension? In how many directions do bodies possess extension? Of what is figure, or form, the result? Do all bodies possess figure? What solids are regular in their forms?

invariable. Some solids are so irregular, that they cannot be compared with any mathematical figure. This is the case with the fragments of a broken rock, chips of wood, fractured glass, &c.

Fluid bodies have no determinate forms, but take their shapes from the vessels in which they happen to be placed.

Divisibility.—By the divisibility of matter, we mean that a body may be divided into parts, and that these parts may again be divided into other parts.

It is quite obvious, that if we break a piece of marble into two parts, these two parts may again be divided, and that the process of division may be continued until these parts are so small as not individually to be seen or felt. But as every body, however small, must possess extension and form, so we can conceive of none so minute but that it may again be divided. There is, however, possibly, a limit, beyond which bodies cannot be actually divided, for there may be reason to believe that the atoms of matter are indivisible by any means in our power. But under what circumstances this takes place, or whether it is in the power of man during his whole life, to pulverize any substance so finely, that it may not again be broken, is unknown.

We can conceive, in some degree, how minute must be the particles of matter, from circumstances that every day come within our knowledge.

A single grain of musk will scent a room for years, and still lose no appreciable part of its weight. Here, the particles of musk must be floating in the air of every part of the room, otherwise they could not be every where perceived.

Gold is hammered so thin, as to take 282,000 leaves to make an inch in thickness. Here, the particles still adhere to each other, notwithstanding the great surface which they cover,—a single grain being sufficient to extend over a surface of fifty square inches.

The ultimate particles of matter, however widely they may be diffused, are not individually destroyed, or lost, but under certain circumstances, may again be collected into a body

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What bodies are irregular? What is meant by divisibility of matter? Is there any limit to the divisibility of matter? Are the atoms of matter divisible? What examples are given of the divisibility of matter? How many leaves of gold does it take to make an inch in thickness? How many square inches may a grain of gold be made to cover?

without change of form. Mercury, water, and many other substances, may be converted into vapor, or distilled in close vessels, without any of their particles being lost. In such cases, there is no decomposition of the substances, but only a change of form by the heat, and hence the mercury and water assume their original state again on cooling.

When bodies suffer decomposition or decay, their elementary particles, in like manner, are neither destroyed nor lost, but only enter into new arrangements, or combinations with other bodies.

When a piece of wood is heated in a close vessel, such as a retort, we obtain water, an acid, several kinds of gas, and there remains a black, porous substance, called charcoal. The wood is thus decomposed, or destroyed, and its particles take a new arrangement, and assume new forms, but that nothing is lost is proved by the fact, that if the water, acid, gases, and charcoal be collected and weighed, they will be found exactly as heavy as the wood was, before distillation.

Bones, flesh, or any animal substance, may in the same manner be made to assume new forms, without losing a particle of the matter which they originally contained.

The decay of animal or vegetable bodies in the open air, or in the ground, is only a process by which the particles of which they were composed, change their places, and assume new forms.

The decay and decomposition of animals and vegetables on the surface of the Earth form the soil, which nourishes the growth of plants and other vegetables; and these, in their turn, form the nutriment of animals. Thus is there a perpetual change from death to life, and from life to death, and as constant a succession in the forms and places, which the particles of matter assume. Nothing is lost, and not a particle of matter is struck out of existence. The same matter of which every living animal, and every vegetable was formed, before and since the flood, is still in existence. As nothing is lost or annihilated, so it is probable that nothing has been added, and that we, ourselves, are composed of particles of

---

Under what circumstances may the particles of matter again be collected in their original form? When bodies suffer decay, are their particles lost? What becomes of the particles of bodies which decay? Is it probable that any matter has been annihilated, or added, since the first creation?

matter as old as the creation. In time, we must, in our turn, suffer decomposition, as all forms have done before us, and thus resign the matter of which we are composed, to form new existences.

Inertia.—Inertia means passiveness or want of power. Thus matter is, of itself, equally incapable of putting itself in motion, or of bringing itself to rest when in motion.

It is plain that a rock on the surface of the earth, never changes its position in respect to other things on the earth. It has of itself no power to move, and would, therefore, for ever lie still, unless moved by some external force. This fact is proved by the experience of every person, for we see the same objects lying in the same positions all our lives. Now, it is just as true, that inert matter has no power to bring itself to rest, when once put in motion, as it is, that it cannot put itself in motion, when at rest, for having no life, it is perfectly passive, both to motion and rest, and therefore either state depends entirely upon circumstances.

Common experience proving that matter does not put itself in motion, we might be led to believe, that rest is the natural state of all inert bodies, but a few considerations will show, that motion is as much the natural state of matter as rest, and that either state depends on the resistance, or impulse, of external causes.

If a cannon ball be rolled upon the ground, it will soon cease to move, because the ground is rough, and presents impediments to its motion; but if it be rolled on the ice, its motion will continue much longer, because there are fewer impediments, and consequently, the same force of impulse will carry it much farther. We see from this, that with the same impulse, the distance to which the ball will move must depend on the impediments it meets with, or the resistance it has to overcome. But suppose that the ball and ice were both so smooth as to remove as much as possible the resistance caused by friction, then it is obvious that the ball would continue to move longer, and go to a greater distance. Next suppose we avoid the friction of the ice, and throw the ball through the air, it would then continue in motion still longer with the same

---

What is said of the particles of matter of which we are made? What does inertia mean? Is rest or motion the natural state of matter? Why does the ball roll farther on the ice than on the ground? What does this prove?

force of projection, because the air alone, presents less impediment than the air and ice, and there is now nothing to oppose its constant motion, except the resistance of the air, and its own weight, or gravity.

If the air be exhausted, or pumped out of a vessel by means of an air pump, and a common top, with a small, hard point, be set in motion in it, the top will continue to spin for hours, because the air does not resist its motion. A pendulum, set in motion, in an exhausted vessel, will continue to swing, without the help of clock work, for a whole day, because there is nothing to resist its perpetual motion, but the small friction at the point where it is suspended.

We see, then, that it is the resistance of the air, of friction, and of gravity, which cause bodies once in motion to cease moving, or come to rest, and that dead matter of itself, is equally incapable of causing its own motion, or its own rest.

We have perpetual examples of the truth of this doctrine, in the moon, and other planets. These vast bodies move through spaces which are void of the obstacles of air and friction, and their motions are the same that they were thousands of years ago, or at the beginning of creation.

Attraction.—By attraction is meant that property, or quality in the particles of bodies, which make them tend toward each other.

We know that substances are composed of small atoms, or particles, of matter, and that it is a collection of these, united together, that forms all the objects with which we are acquainted. Now, when we come to divide, or separate any substance into parts, we do not find that its particles have been united, or kept together by glue, little nails, or any such mechanical means, but that they cling together by some power, not obvious to our senses. This power we call *attraction*, but of its nature or cause, we are entirely ignorant. Experiment and observation, however, demonstrate, that this power pervades all material things, and that under different modifications, it

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Why, with the same force of projection, will a ball move farther through the air than on the ice? Why will a top spin, or a pendulum swing longer, in an exhausted vessel than in the air? What are the causes which resist the perpetual motion of bodies? Where have we an example of continued motion, without the existence of air and friction? What is meant by attraction? What is known about the cause of attraction? Is attraction common to all kinds of matter, or not?

not only makes the particles of bodies adhere to each other, but is the cause which keeps the planets in their orbits as they pass through the heavens.

Attraction has received different names, according to the circumstances under which it acts.

The force which keeps the particles of matter together, to form bodies, or masses, is called *attraction* of *cohesion.* That which inclines different masses towards each other, is called *attraction* of *gravitation.* That which causes liquids to rise in tubes, is called *capillary attraction.* That which forces the particles of substances of different kinds to unite, is known under the name of *chemical attraction.* That which causes the needle to point constantly towards the poles of the earth is *magnetic attraction;* and that which is excited by friction in certain substances, is known by the name of *electrical attraction.*

The following illustrations, it is hoped, will make each kind of attraction distinct and obvious to the mind of the student.

Attraction of cohesion acts only at insensible distances, as when the particles of bodies apparently touch each other.

Take two pieces of lead, of a round form, an inch in diameter, and two inches long; flatten one end of each, and make through it an eye-hole for a string. Make the other ends of each as smooth as possible, by cutting them with a sharp knife. If now the smooth surfaces be brought together, with a slight turning pressure, they will adhere with such force that two men can hardly pull them apart by the two strings.

In like manner, two pieces of plate glass, when their surfaces are cleaned from dust, and they are pressed together, will adhere with considerable force. Other smooth substances present the same phenomena.

This kind of attraction is much stronger in some bodies than in others. Thus, it is stronger in the metals than in most other substances, and in some of the metals it is stronger than in others. In general, it is most powerful among the particles of solid bodies, weaker among those of liquids, and

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What effect does this power have upon the planets? Why has attraction received different names? How many kinds of attraction are there? How does the attraction of cohesion operate? What is meant by attraction of gravitation? What by capillary attraction? What by chemical attraction? What is that which makes the needle point towards the pole? How is electrical attraction excited? Give an example of cohesive attraction.

probably entirely wanting among elastic fluids, such as air, and the gases.

Thus, a small iron wire will hold a suspended weight of many pounds, without having its particles separated; the particles of water are divided by a very small force, while those of air, are still more easily moved among each other. These different properties depend on the force of cohesion with which the several particles of these bodies are united.

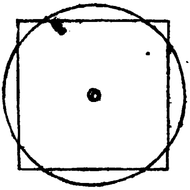
When the particles of fluids are left to arrange themselves according to the laws of attraction, the bodies which they compose assume the form of a globe or ball.

Drops of water thrown on an oiled surface or on wax—globules of mercury,—hail stones,—a drop of water adhering to the end of the finger,—tears running down the cheeks, and dew drops on the leaves of plants, are all examples of this law of attraction. The manufacture of shot is also a striking illustration. The lead is melted and poured into a sieve, at the height of about two hundred feet from the ground. The stream of lead immediately after leaving the sieve, separates into round globules, which, before they reach the ground, are cooled and become solid, and thus are formed the shot used by sportsmen.

To account for the globular form in all these cases, we have only to consider that the particles of matter are mutually attracted towards a common centre, and in liquids being free to move, they arrange themselves accordingly.

In all figures except the globe, or ball, some of the particles must be nearer the centre than others. But in a body that is perfectly round, every part of the outside is exactly at the same distance from the centre.

Fig. 1.



Thus the corners of a cube, or square, are at much greater distances from the centre, than the sides, while the circumference of a circle or ball is every where at the same distance from it. This difference is shown by fig. 1, and it is quite obvious, that if the particles of matter are equally attracted towards the common centre, and are free to arrange themselves, no other figure could

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In what substances is cohesive attraction the strongest? In what substances is it weakest? Why are the particles of fluids more easily separated than those of solids?

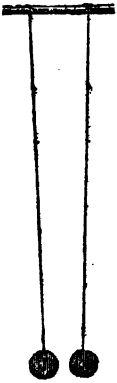
possibly be formed, since then every part of the outside is equally attracted.

The sun, earth, moon, and indeed all the heavenly bodies, are illustrations of this law, and therefore were probably in so soft a state when first formed, as to allow their particles freely to arrange themselves accordingly.

Attraction of gravitation.—As the attraction of cohesion unites the particles of matter into masses or bodies, so the attraction of gravitation tends to force these masses towards each other, to form those of still greater dimensions. The term gravitation, does not here strictly refer to the weight of bodies, but to the attraction of the masses of matter towards each other, whether downwards, upwards, or horizontally.

The attraction of gravitation is mutual, since all bodies not only attract other bodies, but are themselves attracted.

Fig. 2.



Two cannon balls, when suspended by long cords, so as to hang quite near each other, are found to exert a mutual attraction, so that neither of the cords is exactly perpendicular, but they approach each other, as in fig. 2.

In the same manner, the heavenly bodies, when they approach each other, are drawn out of the line of their paths, or orbits, by mutual attraction.

The force of attraction increases in proportion as bodies approach each other, and by the same law it must diminish in proportion as they recede from each other.

Attraction, in technical language, is inversely as the squares of the distances between the two bodies. That is, in proportion as the square of the distance increases, in the same proportion attraction decreases, and so the contrary. Thus, if at the distance of 2 feet, the attraction be equal to 4 pounds, at the

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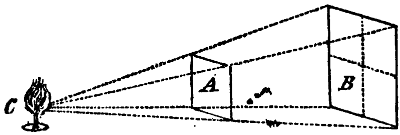
What form do fluids take, when their particles are left to their own arrangement? Give examples of this law. How is the globular form which liquids assume, accounted for? If the particles of a body are free to move, and are equally attracted towards the centre, what must be its figure? Why must the figure be a globe? What great natural bodies are examples of this law? What is meant by attraction of gravitation? Can one body attract another without being itself attracted? How is it proved that bodies attract each other? By what law, or rule, does the force of attraction increase?

distance of 4 feet, it will be only 1 pound; for the square of 2 is 4, and the square of 4 is 16, which is 4 times the square of 2. On the contrary, if the attraction at the distance of 6 feet be 3 pounds, at the distance of 2 feet it will be 9 times as much, or 27 pounds, because 36, the square of 6, is equal to 9 times 4, the square of 2.

The intensity of light is found to increase and diminish in the same proportion. Thus, if a board a foot square, be placed at the distance of one foot from a candle, it will be found to hide the light from another board of two feet square, at the distance of two feet from the candle. Now a board of two feet square is just four times as large as one of one foot square, and therefore the light at double the distance being spread over 4 times the surface, has only one fourth the intensity.

Fig. 3.



This experiment may be easily tried, or may be readily understood by fig. 3, where *c* represents the candle, *A* the small board, and *B* the large one; *B* being four times the size of *A*.

The force of the attraction of gravitation, is in proportion to the quantity of matter the attracting body contains.

Some bodies of the same bulk contain a much greater quantity of matter than others: thus, a piece of lead contains about twelve times as much matter as a piece of cork of the same dimensions, and therefore a piece of lead of any given size, and a piece of cork twelve times as large, will attract each other equally.

Capillary Attraction.—The force by which small tubes, or porous substances, raise liquids above their levels, is called capillary attraction.

If a small glass tube be placed in water, the water on the inside will be raised above the level of that on the outside of

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Give an example of this rule. How is it shown that the intensity of light increases and diminishes in the same proportion as the attraction of matter? Do bodies attract in proportion to bulk, or quantity of matter? What would be the difference of attraction between a cubic inch of lead, and a cubic inch of cork? Why would there be so much difference? What is meant by capillary attraction? How is this kind of attraction illustrated with a glass tube?

the tube. The cause of this seems to be nothing more than the ordinary attraction of the particles of matter for each other. The sides of a small orifice are so near each other, as to attract the particles of the fluid on their opposite sides, and as all attraction is strongest in the direction of the greatest quantity of matter, the water is raised upwards, or in the direction of the length of the tube. On the outside of the tube, the opposite surfaces, it is obvious, cannot act on the same column of water, and therefore the influence of attraction is here hardly perceptible in raising the fluid. This seems to be the reason why the fluid rises higher on the inside than on the outside of the tube.

A great variety of porous substances are capable of this kind of attraction. If a piece of sponge or a lump of sugar be placed, so that its lowest corner touches the water, the fluid will rise up and wet the whole mass. In the same manner, the wick of a lamp will carry up the oil to supply the flame, though the flame is several inches above the level of the oil. If the end of a towel happens to be left in a basin of water, it will empty the basin of its contents. And on the same principle, when a dry wedge of wood is driven into the crevice of a rock, and afterwards moistened with water, as when the rain falls upon it, it will absorb the water, swell, and sometimes split the rock. In Germany, mill-stone quarries are worked in this manner.

Chemical attraction takes place between the particles of substances of different kinds, and unites them into one compound.

This species of attraction takes place only between the particles of certain substances, and is not, therefore, a universal property. It is also known under the name of *chemical affinity*, because it is said, that the particles of substances having an affinity between them, will unite, while those having no affinity for each other do not readily enter into union.

There seems, indeed, in this respect, to be very singular preferences, and dislikes, existing among the particles of matter. Thus, if a piece of marble be thrown into sulphuric acid, their particles will unite with great rapidity, and commotion,

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Why does the water rise higher in the tube, than it does on the outside? Give some common illustrations of this principle. What is the effect of chemical attraction? By what other name is this kind of attraction known? What effect is produced when marble and sulphuric acid are brought together?

and there will result a compound differing in all respects from the acid or the marble. But if a piece of glass, quartz, gold, or silver, be thrown into the acid, no change is produced on either, because their particles have no affinity.

Sulphur and quicksilver, when heated together, will form a beautiful red compound, known under the name of *vermilion*, and which has none of the qualities of sulphur or quicksilver.

Oil and water have no affinity for each other, but potash has an attraction for both, and therefore oil and water will unite when potash is mixed with them. In this manner, the well known article called *soap* is formed. But the potash has a stronger attraction for an acid than it has for either the oil or the water; and therefore when soap is mixed with an acid, the potash leaves the oil, and unites with the acid, thus destroying the old compound, and at the same instant forming a new one. The same happens when soap is dissolved in any water containing an acid, as the water of the sea, and of certain wells. The potash forsakes the oil, and unites with the acid, thus leaving the oil to rise to the surface of the water. Such waters are called *hard*, and will not wash, because the acid renders the potash a neutral substance.

Magnetic Attraction.—There is a certain ore of iron, a piece of which, being suspended by a thread, will always turn one of its sides to the north. This is called the *loadstone*, or *natural Magnet*, and when it is brought near a piece of iron, or steel, a mutual attraction takes place, and under certain circumstances, the two bodies will come together and adhere to each other. This is called *Magnetic Attraction.* When a piece of steel or iron is rubbed with a Magnet, the same virtue is communicated to the steel, and it will attract other pieces of steel, and if suspended by a string, one of its ends will constantly point towards the north, while the other, of course, points towards the south. This is called an *artificial* Magnet. The *magnetic needle* is a piece of steel, first touched with the loadstone, and then suspended, so as to turn easily

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What is the effect when glass and this acid are brought together? What is the reason of this difference? How may oil and water be made to unite? What is the composition thus formed called? How does an acid destroy this compound? What is the reason that hard water will not wash? What is a natural magnet? What is meant by magnetic attraction? What is an artificial magnet? What is a magnetic needle?

on a point. By means of this instrument, the mariner guides his ship through the pathless ocean. *See Magnetism.*

Electrical Attraction.—When a piece of glass, or sealing wax, is rubbed with the dry hand, or a piece of cloth, and then held towards any light substance, such as hair, or thread, the light body will be attracted by it, and will adhere for a moment to the glass or wax. The influence which thus moves the light body is called *Electrical Attraction.* When the light body has adhered to the surface of the glass for a moment, it is again thrown off, or repelled, and this is called *Electrical Repulsion.* *See Electricity.*

We have thus described and illustrated all the universal or inherent properties of bodies, and have also noticed the several kinds of attraction which are peculiar, namely, Chemical, Magnetic, and Electrical. There are still several properties to be mentioned. Some of them belong to certain bodies in a peculiar degree, while other bodies possess them but slightly. Others belong exclusively to certain substances, and not at all to others. These properties are as follows.

Density.—This property relates to the compactness of bodies, or the number of particles which a body contains within a given bulk. It is closeness of texture. Bodies which are most dense, are those which contain the least number of pores. Hence the density of the metals is much greater than the density of wood. Two bodies being of equal bulk, that which weighs most, is most dense. Some of the metals may have this quality increased by hammering, by which their pores are filled up and their particles are brought nearer to each other. The density of air is increased by forcing more into a close vessel than it naturally contained.

Rarity.—This is the quality opposite to density, and means that the substance to which it is applied is porous, and light. Thus air, water, and ether, are rare substances, while gold, lead, and platina, are dense bodies.

Hardness.—This property is not in proportion, as might be expected, to the density of the substance, but to the force with which the particles of a body cohere, or keep their

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What is its use? What is meant by electrical attraction? What is electrical repulsion? What is density? What bodies are most dense? How may this quality be increased in the metals? What is rarity?—What are rare bodies? What are dense bodies? How does hardness differ from density?

places. Glass, for instance, will scratch gold or platina, though these metals are much more dense than glass. It is probable, therefore, that these metals contain the greatest number of particles, but that those of the glass are more firmly fixed in their places.

Some of the metals can be made hard or soft at pleasure. Thus steel when heated, and then suddenly cooled, becomes harder than glass, while if allowed to cool slowly, it is soft and flexible.

Elasticity is that property in bodies by which, after being forcibly compressed or bent, they regain their original state when the force is removed.

Some substances are highly elastic, while others want this property entirely. The separation of two bodies after impact, or striking together, is a proof that one or both are elastic. In general, most hard and dense bodies, possess this quality in greater or less degree. Ivory, glass, marble, flint, and ice, are elastic solids. An ivory ball, dropped upon a marble slab, will bound nearly to the height from which it fell, and no mark will be left on either. India rubber is exceedingly elastic, and on being thrown forcibly against a hard body, will bound to an amazing distance.

Putty, dough, and wet clay, are examples of the entire want of elasticity, and if either of these be thrown against an impediment, they will be flattened, stick to the place they touch, and never, like elastic bodies, regain their former shapes.

Among fluids, water, oil, and in general all such substances as are denominated liquids, are nearly inelastic, while air and the gaseous fluids, are the most elastic of all bodies.

Brittleness is the property which renders substances easily broken, or separated into irregular fragments. This property belongs chiefly to hard bodies.

It does not appear that brittleness is entirely opposed to elasticity, since in many substances, both these properties are united. Glass is the standard, or type of brittleness, and yet

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Why will glass scratch gold or platina? What metal can be made hard or soft at pleasure? What is meant by elasticity? How is it known that bodies possess this property? Mention several elastic solids. Give examples of inelastic solids. Do liquids possess this property? What are the most elastic of all substances? What is brittleness? Are brittleness and elasticity ever found in the same substance? Give examples.

a ball, or fine threads of this substance are highly elastic, as may be seen by the bounding of the one, and the springing of the other. Brittleness often results from the treatment to which substances are submitted. Iron, steel, brass, and copper, become brittle when heated and suddenly cooled, but if cooled slowly, they are not easily broken.

Malleability.—Capability of being drawn under the hammer, or rolling press. This property belongs to some of the metals, but not to all, and is of vast importance to the arts and conveniences of life.

The Malleable metals are, gold, silver, iron, copper, and some others. Antimony, bismuth, and cobalt, are brittle metals. Brittleness is therefore the opposite of malleability.

Gold is the most malleable of all substances. It may be drawn under the hammer so thin that light may be seen through it. Copper and silver are also exceedingly malleable.

Ductility, is that property in substances which renders them susceptible of being drawn into wire.

We should expect that the most malleable metals would also be the most ductile; but experiment proves that this is not the case. Thus, tin and lead may be drawn into thin leaves, but cannot be drawn into small wire. Gold is the most malleable of all the metals, but platina is the most ductile. Dr. Wollaston drew platina into threads not much larger than a spider's web.

Tenacity, in common language called *toughness*, refers to the force of cohesion among the particles of bodies. Tenacious bodies are not easily pulled apart. There is a remarkable difference in the tenacity of different substances. Some possess this property in a surprising degree, while others are torn asunder by the smallest force.

Among the malleable metals, iron and steel are the most tenacious, while lead is the least so. Steel is by far the most tenacious of all known substances. A wire of this metal no larger than the hundredth part of an inch in diameter sustained a weight of 134 pounds, while a wire of platina of

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How are iron, steel, and brass, made brittle? What does malleability mean? What metals are malleable, and what ones are brittle? Which is the most malleable metal? What is meant by ductility? Are the most malleable metals, the most ductile? What is meant by tenacity? From what does this property arise? What metals are most tenacious?

the same size, would sustain a weight of only 16 pounds, and one of lead only 2 pounds. Steel wire will sustain 39,000 feet of its own length without breaking.

Recapitulation.—The common, or essential properties of bodies are, Impenetrability, Extension, Figure, Divisibility Inertia, and Attraction. Attraction is of several kinds, namely, Attraction of cohesion, Attraction of gravitation, Capillary attraction, Chemical attraction, Magnetic attraction, and Electrical attraction.

The peculiar properties of bodies are, Density, Rarity, Hardness, Elasticity, Brittleness, Malleability, Ductility, and Tenacity.

Force of Gravity.

The force by which bodies are drawn towards each other in the mass, and by which they descend towards the earth when suspended or let fall from a height, is called the force of *gravity.*

The attraction which the earth exerts on all bodies near its surface, is called *terrestrial gravity,* and the force with which any substance is drawn downwards, is called its *weight.*

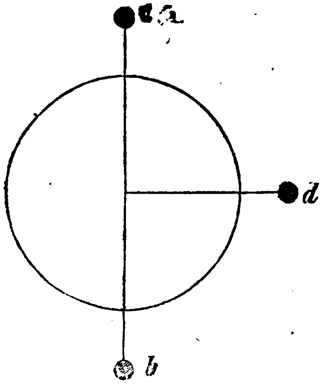
All falling bodies tend downwards towards the centre of the earth, in a straight line from the point where they are let fall. If then a body be let fall in any part of the world, the line of its direction will be perpendicular to the earth's surface. It follows, therefore, that two falling bodies, on opposite parts of the earth, mutually fall towards each other.

Suppose a cannon ball to be disengaged from a height opposite to us, on the other side of the earth, its motion in respect to us, would be upward, while the downward motion from where we stand, would be upward in respect to those who stand opposite to us, on the other side of the earth.

In like manner, if the falling body be a quarter, instead of half the distance round the earth from us, its line of direction would be directly across, or at right angles with the line already supposed.

What proportion does the tenacity of steel bear to that of platina and lead? What are the essential properties of bodies? How many kinds of attraction are there? What are the peculiar properties of bodies? What is gravity? What is terrestrial gravity? To what point in the earth do falling bodies tend? In what direction will two falling bodies from opposite parts of the earth tend, in respect to each other? In what direction will one from half way between them meet their line?

Fig. 4.



This will be readily understood by fig. 4, where the circle is supposed to be the circumference of the earth, *a*, the ball falling towards its upper surface, where we stand; *b*, a ball falling towards the opposite side of the earth, but ascending in respect to us, and *d*, a ball descending at the distance of a quarter of the circle, from the other two, and crossing the line of their direction at right angles.

It will be obvious, therefore, that what we call *up* and *down* are merely relative terms, and that what is down in respect to us, is up in respect to those who live on the opposite side of the earth, and so the contrary. Consequently *down*, every where means towards the centre of the earth, and *up* from the centre of the earth; because all bodies descend towards the earth's centre, from whatever part they are let fall. This will be apparent when we consider, that as the earth turns over every 24 hours, we are carried with it through the points *a*, *d*, and *b*, fig. 4; and therefore, if a ball is supposed to fall from the point *a*, say at 12 o'clock and the same ball to fall again from the same point above the earth, at 6 o'clock, the two lines of direction will be at right angles, as represented in the figure, for that part of the earth which was under *a* at 12 o'clock, will be under *d* at 6 o'clock, the earth having in that time performed one quarter of its daily revolution. At 12 o'clock at night, if the ball be supposed to fall again, its line of direction will be at right angles with that of its last descent, and consequently it will *ascend* in respect to the point on which it fell 12 hours before, because the earth would

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How is this shown by the figure? Are the terms *up* and *down* relative, or positive, in their meaning? What is understood by *down* in any part of the earth? Suppose a ball be let fall at 12 and then at 6 o'clock, in what direction would the lines of their descent meet each other? Suppose two balls to descend from opposite sides of the earth, what would be their direction in respect to each other?

have then gone through one half her daily rotation, and the point *a* would be at *b*.

The velocity or rapidity of every falling body, is uniformly accelerated, or increased in its approach towards the earth, from whatever height it falls.

If a rock is rolled from a steep mountain, its motion is at first slow and gentle, but as it proceeds downward, it moves with perpetually increased velocity, seeming to gather fresh speed every moment, until its force is such that every obstacle is overcome; trees and rocks are beat from its path, and its motion does not cease until it has rolled to a great distance on the plain.

The same principle of increased velocity as bodies descend from a height, is curiously illustrated by pouring molasses or thick syrup from an elevation to the ground. The bulky stream, of perhaps two inches in diameter, where it leaves the vessel, as it descends, is reduced to the size of a straw, or knitting needle; but what it wants in bulk is made up in velocity, for the small stream at the ground, will fill a vessel just as soon as the large one at the outlet.

For the same reason, a man may leap from a chair without danger, but if he jumps from the house top, his velocity becomes so much increased, before he reaches the ground, as to endanger his life by the blow.

It is found by experiment, that the motion of a falling body is increased, or accelerated in regular mathematical proportions.

These increased proportions do not depend on the increased weight of the body, because it approaches nearer the centre of the earth, but on the constant operation of the force of gravity, which perpetually gives new impulses to the falling body, and increases its velocity.

It has been ascertained by experiment, that a body, falling freely, and without resistance, passes through a space of 16 feet and 1 inch during the first second of time. Leaving out the inch, which is not necessary for our present purpose, the ratio of descent is as follows.

Suppose the body falls through a space equal to 16 feet the

What is said concerning the motions of falling bodies? How is this increased velocity illustrated? Why is there any more danger in jumping from the house top than from a chair? What number of feet does a falling body pass through during the first second?

first second of time; at the end of this space and time, it will have acquired such a degree of celerity as is sufficient to carry it through twice this space during the next second, though it should then receive no new impulse from the cause by which its motion had been accelerated; but if the same accelerating cause continue, it will carry the body 16 feet further; on which account, it will have fallen in all four times 16 feet, or 64 feet at the end of the second second; and then it will have acquired such a degree of celerity as is sufficient to carry it through a double space in as much more time; that is 4 times 16 feet in one second more, even though the force of gravity or the accelerating force should cease to act. But this force still continuing to act in a uniform manner, it will again in equal time produce an equal effect, and will therefore add 16 feet to the velocity already acquired, at the end of the second second, which being 64 feet, it will fall 80 feet, or five times as far the third second, as it did the first. In three seconds, the velocity acquired will be 3 times that acquired at the end of the first second, which being twice 16 feet, is equal to 6 times 16 feet, to which, again, is to be added the accelerating force 16 feet, making 7 times 16 feet for the space passed through during the fourth second.

Hence we learn that if a body moves at the rate of 16 feet during the first second, it will move 48 feet during the next second, making in all 64 feet at the end of the second second, 5 times 16 during the third, or 80 feet, and 7 times 16, or 112 feet, in the 4th second, and so on in this proportion.

Thus it appears, that to ascertain the velocity with which a body falls in any given time, we must know how many feet it fell during the first second. The velocity acquired in one second, and the space fallen through during that time, being the fundamental elements of the whole calculation, and all that are necessary for the computation of the various circumstances of falling bodies.

The difficulty of calculating exactly the velocity of a falling body from an actual measurement of its height, and the time

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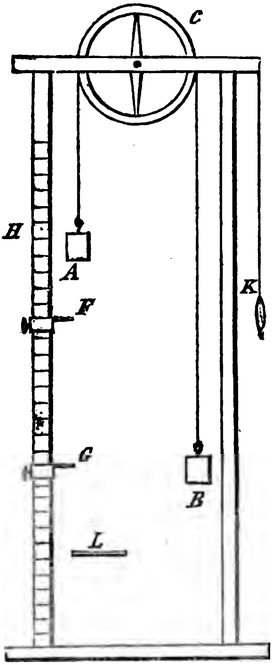
How far does it fall during the next second? How far during the third? Suppose the accelerating force should cease at the beginning of the third second; how far would it fall during that second? Why does it fall more than this during that second? How many times 16 feet does a body move in the 4th second? What are the fundamental elements by which the velocity of a falling body may be computed?

which it takes to reach the ground, is so great, that no accurate computation could be made from such an experiment.

This difficulty has, however, been overcome by a curious piece of machinery, invented for this purpose by Mr. Atwood.

Fig. 5.



This machine consists of two upright posts of wood, fig. 5 with cross pieces, as shown in the figure. The weights *A* and *B*, are of the same size, and made to balance each other very exactly, and are connected by the thread which passes over the wheel *C*. *F* is a ring through which the weight *A* passes, and *G* is a stage on which the weight rests in its descent. The ring and stage both slide up and down, and are fixed at pleasure by thumb screws. The post *H*, is a graduated scale, and the pendulum *K*, is kept in motion by clock-work. *L*, is a small bar of metal, weighing a quarter of an ounce, and longer than the diameter of the ring *F*.

When the machine is to be used, the weight *A* is drawn up to the top of the scale, and the ring and stage are placed a certain number of inches from each other. The small bar *L*, is then placed across the weight *A*, by means of which it is made slowly to descend. When it has descended to the ring, the small weight *L*, is taken off by the ring, and thus the two weights are left equal to each other. Now it must be observed, that the motion, and descent of the weight *A* is entirely owing to the gravitating force of the weight *L*, until it arrives at the ring *F*, when the action of gravity is suspended, and the large weight

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Is the velocity of a falling body calculated from actual measurement, or by a machine? Describe the operation of Mr. Atwood's machine for estimating the velocities of falling bodies.

continues to move downwards to the stage, in consequence of the velocity it had acquired previously to that time.

To comprehend the accuracy of this machine, it must be understood that the velocities of gravitating bodies are supposed to be equal, whether they are large or small, this being the case when no calculation is made for the resistance of the air. Consequently, the weight of a quarter of an ounce placed on the large weight *A*, is a representative of all other solid descending bodies. The slowness of its descent, when compared with freely gravitating bodies, is only a convenience by which its motion can be accurately measured, for it is the *increase* of velocity which the machine is designed to ascertain and not the *actual* velocity of falling bodies.

Now it will be readily comprehended, that in this respect, it makes no difference how slowly a body falls, *provided it follows the same laws as other descending bodies*, and it has already been stated, that all estimates on this subject are made from the known distance a body descends during the first second of time.

It follows, therefore, that if it can be ascertained, exactly how much faster a body falls during the third, fourth, or fifth second, than it did during the first second, by knowing how far it fell during the first second, we should be able to estimate the distance it would fall during all succeeding seconds.

If, then, by means of a pendulum beating seconds, the weight *A* should be found to descend a certain number of inches during the first second, and another certain number during the next second, and so on, the ratio of increased descent would be precisely ascertained, and could be easily applied to the falling of other bodies; and this is the use to which this instrument is applied.

By this machine, it can also be ascertained, how much the actual velocity of a falling body depends on the force of gravity, and how much on acquired velocity, for the force of gravity gives motion to the descending weight only until it arrives at

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After the small weight is taken off by the ring why does the large weight continue to descend? Does this machine show the actual velocity of a falling body, or only its increase? How does Mr. Atwood's machine show how much the celerity of a body depends upon gravity, and how much on acquired velocity?

the ring, after which the motion is continued by the velocity it had before acquired.

From experiments accurately made with this machine, it has been fully established, that if the time of a falling body be divided into equal parts, say into seconds, the spaces through which it falls in each second, taken separately, will be as the odd numbers, 1, 3, 5, 7, 9, and so on, as already stated. To make this plain, suppose the times occupied by the falling body to be 1, 2, 3, and 4 seconds; then the spaces fallen through will be as the squares of these seconds, or times, viz. 1, 4, 9, and 16, the square of 1 being 1, the square of 2 being 4, the square of 3, 9, and so on. The distance fallen through, therefore, during the second second, may be found, by taking 1, the distance corresponding to one second, from 4, the distance corresponding to 2 seconds, and is therefore 3. For the 3d second, take 4 from 9, and therefore the distance will be 5. For the fourth second, take 9 from 16, and the distance will be 7, and so on. During the first second, then, the body falls a certain distance, during the next second, it falls three times that distance, during the third, five times that distance, during the fourth, seven times that distance, and so continually in that proportion.

It will be readily conceived, that solid bodies falling from great heights, must ultimately acquire an amazing velocity by this proportion of increase. An ounce ball of lead, let fall from a certain height towards the earth, would thus acquire a force ten or twenty times as great as when shot out of a rifle. By actual calculation, it has been found that were the moon to lose her projectile force, which counterbalances the earth's attraction, she would fall to the earth in four days and twenty hours, a distance of 240,000 miles. And were the earth's projectile force destroyed, it would fall to the sun in sixty-four days and ten hours, a distance of 95,000,000 of miles.

Every one knows by his own experience the different

Suppose the times of a falling body are as the numbers 1, 2, 3, 4, what will be the numbers representing the spaces through which it falls? Suppose a body falls 16 feet the first second, how far will it fall the third second? Would it be possible for a rifle ball to acquire a greater force by falling, than if shot from a rifle? How long would it take the Moon to come to the earth according to the law of increased velocity? How long would it take the earth to fall to the sun?

effects of the same body falling from a great or a small height. A boy will toss up his leaden bullet and catch it with his hand, but he soon learns, by its painful effects, not to throw it too high. The effects of hail-stones on window glass, animals, and vegetation, are often surprising, and sometimes calamitous illustrations of the velocity of falling bodies.

It has been already stated that the velocities of solid bodies falling from a given height, towards the earth, are equal, or in other words, that an ounce ball of lead will descend in the same time as a pound ball of lead.

This is true in theory, but there is a slight difference in this respect in favor of the velocity of the larger body, owing to the resistance of the atmosphere. We, however, shall at present consider all solids of whatever size, as descending through the same spaces in the same times, this being exactly true when they pass without resistance.

To comprehend the reason of this we have only to consider, that the attraction of gravitation in acting on a mass of matter acts on every particle it contains; and thus every particle is drawn down equally and with the same force. The effect of gravity, therefore, is in exact proportion to the quantity of matter the mass contains, and not in proportion to its bulk. A ball of lead of a foot in diameter, and one of wood of the same diameter, are obviously of the same bulk; but the lead will contain twelve particles of matter where the wood contains one, and consequently will be attracted with twelve times the force, and therefore will weigh twelve times as much.

If then, bodies attract each other in proportion to the quantities of matter they contain, it follows that if the mass of the earth were doubled, the weights of all bodies on its surface would also be doubled; and if its quantity of matter were tripled, all bodies would weigh three times as much as they do at present.

It follows also, that two attracting bodies, when free to move, must approach each other mutually. If the two bodies

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What familiar illustrations are given of the force acquired by the velocity of falling bodies? Will a small and a large body fall through the same space in the same time? On what parts of a mass of matter does the force of gravity act? Is the effect of gravity in proportion to bulk, or quantity of matter? Were the mass of the earth doubled, how much more should we weigh than we do now?

contain like quantities of matter, their approach will be equally rapid, and they will move equal distances towards each other. But if the one be small and the other large, the small one will approach the other with a rapidity proportioned to the less quantity of matter it contains.

It is easy to conceive, that if a man in one boat pulls at a rope attached to another boat, the two boats, if of the same size, will move towards each other at the same rate; but if the one be large and the other small, the rapidity with which each moves will be in proportion to its size, the large one moving with as much less velocity as its size is greater.

A man in a boat pulling a rope attached to a ship, seems only to move the boat, but that he really moves the ship is certain, when it is considered, that a thousand boats pulling in the same manner would make the ship meet them half way.

It appears, therefore, that an equal force acting on bodies containing different quantities of matter, move them with different velocities, and that these velocities are in an inverse proportion to their quantities of matter.

In respect to *equal forces*, it is obvious that in the case of the ship and single boat, they were moved towards each other by the same force, that is, the force of a man pulling by a rope. The same principle holds in respect to attraction, for all bodies attract each other equally, according to the quantities of matter they contain, and since all attraction is mutual, no body attracts another with a greater force than that by which it is attracted.

Suppose a body to be placed at a distance from the earth weighing two hundred pounds; the earth would then attract the body with a force equal to two hundred pounds, and the body would attract the earth with an equal force, otherwise their attraction would not be equal and mutual. Another body weighing 10 pounds, would be attracted with a force equal to 10 pounds, and so of all bodies according to the quantity of

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Suppose one body moving towards another, three times as large, by the force of gravity, what would be their proportional velocities? How is this illustrated? Does a large body attract a small one with any more force than it is attracted? Suppose a body weighing 200 pounds to be placed at a distance from the earth, with how much force does the earth attract the body? With what force does the body attract the earth?

matter they contain; each body being attracted by the earth with a force equal to its own weight, and attracting the earth with an equal force.

If the man in the boat pulled the rope with the force of 100 pounds, it is plain that the force on each vessel would be 50 pounds; for suppose each end of the rope to be thrown over a pulley, and a weight of 50 pounds attached to these ends, it would take just 100 pounds in the middle of the rope to balance them.

It is inferred from these principles, that all attracting bodies which are free to move, mutually approach each other, and therefore that the earth moves towards every body which is raised from its surface, with a velocity and to a distance proportional to the quantity of matter thus elevated from its surface. But the velocity of the earth being as many times less than that of the falling body as its mass is greater, it follows that its motion is not perceptible to us.

The following calculation will show what an immense mass of matter it would take, to disturb the earth's gravity in a perceptible manner.

If a ball of earth equal in diameter to the tenth part of a mile, were placed at the distance of the tenth part of a mile from the earth's surface, the attracting powers of the two bodies would be in the ratio of about 512 millions of millions to one. For the earth's diameter being about 8000 miles, the two bodies would bear to each other about this proportion. Consequently if the tenth part of a mile were divided into 512 million of millions of equal parts, one of these parts would be nearly the space through which the earth would move towards the falling body. Now in the tenth part of a mile there are about 6400 inches, consequently this number must be divided into 512 millions of millions of parts, which would give the eighty thousand millionth part of an inch through which the earth would move to meet a body of the tenth part of a mile in diameter.

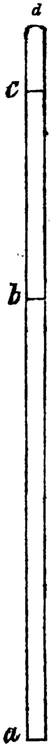
Suppose a man in one boat, pulls with the force of 100 pounds at a rope fastened to another boat, what would be the force on each boat? How is this illustrated? Suppose the body falls towards the earth, is the earth set in motion by its attraction? Why is not the earth's motion towards it perceptible? What distance would a body, the tenth part of a mile in diameter, placed at the distance of a tenth part of a mile, attract the earth towards it?

Ascent of Bodies.

Having now explained and illustrated the influence of gravity on bodies moving downward and horizontally, it remains to show how matter is influenced by the same power when bodies are moved upward, or contrary to the force of gravity.

What has been stated in respect to the velocity of falling bodies is exactly reversed in respect to those which are thrown upwards, for as the motion of a falling body is increased by the action of gravity, so is it retarded by the same force, when thrown upwards.

Fig. 6.



A bullet shot upwards, every instant loses a part of its velocity, until having arrived at the highest point from whence it was thrown, it then returns again to the earth.

The same law that governs a descending body, governs an ascending one, only that their motions are reversed.

The same ratio is observed to whatever distance the ball is propelled, or as the height to which it is thrown may be estimated from the space it passes through during the first second, so its returning velocity is in a like ratio to the height to which it was sent.

This will be understood by fig. 6. Suppose a ball to be propelled from the point *a*, with a force which would carry it to the point *b* in the first second, to *c* in the next, and to *d* in the third second. It would then remain nearly stationary for an instant, and in returning, would pass through exactly the same spaces in the same times, only that its direction would be reversed. Thus it will fall from *d* to *c*, in the first second, to *b* in the next, and to *a* in the third.

Now the force of a moving body is as its velocity and its quantity of matter, and hence the same ball will fall with exactly the same force that it rises. For instance, a ball shot out of a rifle, with a force sufficient to overcome a certain impediment, on returning, would again overcome the same impediment.

What effect does the force of gravity have on bodies moving upward? Are upward and downward motion governed by the same laws? Explain fig. 6. What is the difference between the upward and returning velocity of the same body?

Fall of Light Bodies.

It has been stated that the earth's attraction acts equally on all bodies, containing equal quantities of matter, and that in vacuo, all bodies, whether large or small, descend from the same heights in the same times.

There is, however, a great difference in the quantities of matter which bodies of the same bulk contain, and consequently a difference, in the resistance which they meet with in passing through the air.

Now, the fall of a body containing a large quantity of matter in a small bulk, meets with little comparative resistance, while the fall of another, containing the same quantity of matter, but of larger size, meets with more in comparison, for it is easy to see that two bodies of the same size meet with exactly the same actual resistance. Thus, if we let fall a ball of lead, and another of cork, of two inches in diameter each, the lead will reach the ground before the cork, because, though meeting with the same resistance, the lead has the greatest power of overcoming it.

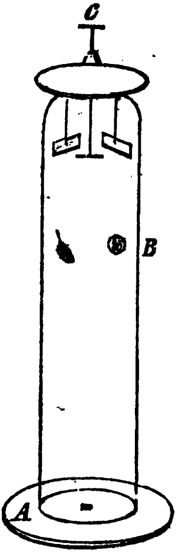
This, however, does not affect the truth of the general law already established, that the weights of bodies are as the quantities of matter they contain. It only shows that the pressure of the atmosphere prevents bulky and porous substances from falling with the same velocity with such as are compact or dense.

Were the atmosphere removed, all bodies, whether light or heavy, large or small, would descend with the same velocity. This fact has been ascertained by experiment in the following manner:

The *air pump* is an instrument, by means of which the air can be pumped out of a close vessel, as will be seen under the article Pneumatics. Taking this for granted at present, the experiment is made in the following manner:

Why will not a sack of feathers and a stone of the same size fall through the air in the same time? Does this affect the truth of the general law that the weights of bodies are as their quantities of matter? What would be the effect on the fall of light and heavy bodies, were the atmosphere removed?

Fig. 7.



On the plate of the air pump *A*, place the tall jar *B*, which is open at the bottom, and has a brass cover fitted closely to the top. Through the cover let a wire pass, air tight, having a small cross at the lower end. On each side of this cross, place a little stage, and so contrive them that by turning the wire by the handle *C*, these stages shall be upset. On one of the stages place a guinea or any other heavy body, and on the other place a feather. When this is arranged, let the air be exhausted from the jar by the pump, and then turn the handle *C*, so that the guinea and feather may fall from their places, and it will be found that they will both strike the plate at the same instant. Thus is it demonstrated, that were it not for the resistance of the atmosphere, a bag of feathers and one of guineas would fall from a given height with the same velocity and in the same time.

Motion.

Motion may be defined, a continued change of place with regard to a fixed point.

Without motion there would be no rising or setting of the sun—no change of seasons—no fall of rain—no building of houses, and finally no animal life. Nothing can be done without motion, and therefore without it, the whole universe would be at rest and dead.

In the language of philosophy, the power which puts a body in motion, is called *force*. Thus it is the force of gravity that overcomes the *inertia* of bodies, and draws them towards the earth. The force of water and steam gives motion to machinery, &c.

For the sake of convenience, and accuracy in the application of terms, motion is divided into two kinds, viz. *absolute* and *relative*.

How is it proved that a feather and a guinea will fall through equal spaces in the same time, where there is no resistance? How will you define motion? What would be the consequence, were all motion to cease? What is that power called which puts a body in motion? How is motion divided?

Absolute motion is a change of place with regard to a fixed point, and is estimated without reference to the motion of any other body. When a man rides along the street, or when a vessel sails through the water, they are both in absolute motion.

Relative motion, is a change of place in a body, with respect to another body, also in motion, and is estimated from that other body, exactly as absolute motion is, from a fixed point.

The absolute velocity of the earth in its orbit from west to east, is 68,000 miles in an hour; that of Mars, in the same direction, is 55,000 miles per hour. The earth's relative velocity in this case, is 13,000 miles per hour from west to east. That of Mars comparatively, is 13,000 miles from east to west, because the earth leaves Mars that distance behind her, as she would leave a fixed point.

Rest, in the common meaning of the term, is the opposite of motion, but it is obvious, that rest is often a relative term, since an object may be perfectly at rest with respect to some things, and in rapid motion in respect to others. Thus a man sitting on the deck of a steam-boat, may move at the rate of fifteen miles an hour, with respect to the land, and still be at rest with respect to the boat. And so, if another man was running on the deck of the same boat at the rate of fifteen miles the hour in a contrary direction, he would be stationary in respect to a fixed point, and still be running with all his might, with respect to the boat.

Velocity of Motion.

Velocity is the rate of motion at which a body moves from one place to another.

Velocity is independent of the weight or magnitude of the moving body. Thus a cannon ball and a musket ball, both flying at the rate of a thousand feet in a second, have the same velocities.

Velocity is said to be *uniform,* when the moving body passes over equal spaces in equal times. If a steam-boat moves at the rate of 10 miles every hour, her velocity is uniform. The revolution of the earth from west to east is a perpetual example of uniform motion.

What is absolute motion? What is relative motion? What is the earth's relative velocity in respect to Mars? In what respect is a man in a steam-boat at rest, and in what respect does he move? What is velocity? When is velocity uniform?

Velocity is *accelerated*, when the rate of motion is constantly increased, and the moving body passes through unequal spaces in equal times. Thus, when a falling body moves sixteen feet during the first second, and forty-eight feet during the next second, and so on, its velocity is accelerated. A body falling from a height freely through the air, is the most perfect example of this kind of velocity.

Retarded velocity, is when the rate of motion of the body is constantly decreased, and it is made to move slower and slower. A ball thrown upwards into the air, has its velocity constantly retarded by the attraction of gravitation, and consequently, it moves slower every moment.

Force, or Momentum of Moving Bodies.

The velocities of bodies are equal, when they pass over equal spaces in the same time; but the force with which bodies, moving at the same rate, overcome impediments, is in proportion to the quantity of matter they contain. This power, or force, is called the *momentum* of the moving body.

Thus, if two bodies of the same weight move with the same velocity, their momenta will be equal.

Two vessels, each of a hundred tons, sailing at the rate of six miles an hour, would overcome the same impediments, or be stopped by the same obstructions. Their momenta would therefore be the same.

The force, or momentum of a moving body, is in proportion to its quantity of matter, and its velocity.

A large body moving slowly, may have less momentum than a small one moving rapidly. Thus, a bullet, shot out of a gun, moves with much greater force than a stone thrown by the hand. The momentum of a body is found by multiplying its quantity of matter by its velocity.

Thus, if the velocity be 2, and the weight 2, the momentum will be 4. If the velocity be 6 and the weight of the body 4, the momentum will be 24.

If a moving body strikes an impediment, the force with which it strikes, and the resistance of the impediment, are equal. Thus, if a boy throw his ball against the side of the

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When is velocity accelerated? Give illustrations of these two kinds of velocity. What is meant by retarded velocity? Give an example of retarded velocity. What is meant by the momentum of a body? When will the momenta of two bodies be equal? Give an example. When has a small body more momentum than a large one? By what rule is the momentum of a body found?

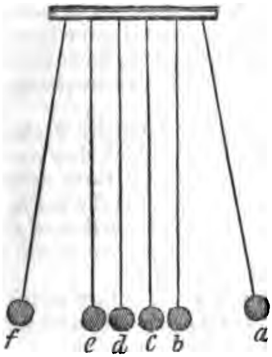
house, with the force of 3, the house resists it with an equal force, and the ball rebounds. If he throws it against a pane of glass with the same force, the glass having only the power of 2 to resist, the ball will go through the glass, still retaining one third of its force.

From observations made on the effects of bodies striking each other, it is found that action and re-action are equal; or, in other words, that force and resistance are equal. Thus, when a moving body strikes one that is at rest, the body at rest returns the blow with equal force.

This is illustrated by the well known fact, that if two persons strike their heads together, one being in motion, and the other at rest, they are both equally hurt.

The philosophy of action and re-action is finely illustrated by a number of ivory balls, suspended by threads, as in fig. 10, so as to touch each other. If the ball *a* be drawn from the perpendicular, and then let fall, so as to strike the one next to it, the motion of the falling ball will be communicated through the whole series, from one to the other. None of the balls, except *f*, will however, appear to move. This will be understood, when we consider that the re-action of *b*, is just equal to the action of *a*, and that each of the other balls, in like manner, acts, and re-acts, on the other, until the motion of *a* arrives at *f*, which, having no impediment, or nothing to act upon, is itself put in motion. It is, therefore, re-action, which causes all the balls, except *f*, to remain at rest.

Fig. 10.



It is by a modification of the same principle, that rockets are impelled through the air. The stream of expanded air, or the fire which is emitted from the lower end of the rocket, not only propels against the rocket itself, but against the atmospheric air, which, re-acting against the air so expanded, sends the rocket along.

When a moving body strikes an impediment, which receives the greatest shock? What is the law of action and re-action? How is this illustrated? When one of the ivory balls strikes the other, why does the most distant one only move? On what principle are rockets impelled through the air?

It was on account of not understanding the principles of action and re-action, that the man undertook to make a fair wind for his pleasure boat to be used whenever he wished to sail. He fixed an immense bellows in the stern of his boat, not doubting but the wind from it would carry him along. But on making the experiment, he found that his boat went backwards, instead of forwards. The reason is plain. The re-action of the atmosphere on the stream of wind from the bellows, before it reached the sail, moved the boat in a contrary direction. Had the sails received the whole force of the wind from the bellows, the boat would not have moved at all, for then, action and re-action would have been exactly equal, and it would have been like a man's attempting to raise himself over a fence by the straps of his boots.

Reflected Motion.

It has been stated that all bodies when once set in motion, would continue to move straight forward, until some impediment, acting in a contrary direction, should bring them to rest; continued motion without impediment being a consequence of the inertia of matter.

Such bodies are supposed to be acted upon by a single force, and that in the direction of the line in which they move. Thus, a ball sent out of a gun, or struck by a bat, turns neither to the right, nor left, but makes a curve towards the earth, in consequence of another force, which is the attraction of gravitation, and by which, together with the resistance of the atmosphere, it is finally brought to the ground.

The kind of motion now to be considered, is that which is produced when bodies are turned out of a straight line by some force, independent of gravity.

A single force, or impulse, sends the body directly forward, but another force, not exactly coinciding with this, will give it a new direction, and bend it out of its former course.

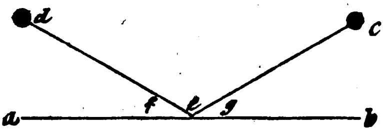
If, for instance, two moving bodies strike each other obliquely, they will both be thrown out of the line of their former direction. This is called *reflected* motion, because, it observes the same laws as reflected light.

In the experiment with the boat and bellows, why did the boat move backwards? Why would it not have moved at all, had the sail received all the wind from the bellows? Suppose a body is acted on, and set in motion by a single force, in what direction will it move? What is the motion called, when a body is turned out of a straight line by another force?

The bounding of a ball; the skipping of a stone over the smooth surface of a pond; and the oblique direction of an apple, when it touches a limb in its fall, are examples of reflected motion.

By experiments on this kind of motion, it is found, that moving bodies observe certain laws, in respect to the direction they take in rebounding from any impediment they happen to strike. Thus, a ball, striking on the floor, or wall of a room, makes the same angle in leaving the point where it strikes, that it does in approaching it.

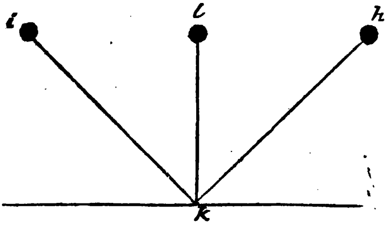
Fig. 11.



Suppose *a*, *b*, fig. 11, to be a marble slab, or floor, and *c* to be an ivory ball, which has been thrown towards the floor in the direction of the line *c*, *e*; it will rebound in the direction of the line *e*, *d*, thus making the two angles *f* and *g* exactly equal.

If the ball approached the floor under a larger or smaller angle, its rebound would observe the same rule. Thus, if it

Fig. 12.



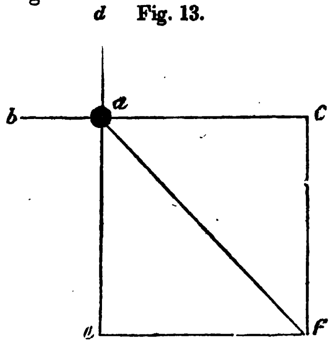
fell in the line *h k*, fig. 12, its rebound would be in the line *k i*, and if it was dropped perpendicularly from *l* to *k*, it would return in the same line to *l*. The angle which the ball makes with the perpendicular *l k*, in its approach to the floor is called the *angle of incidence*, and that which it makes in departing from the floor in the same line, is called the *angle of reflection*, and these angles are always equal to each other.

What illustrations can you give of reflected motion? What laws are observed in reflected motion? Suppose a ball to be thrown on the floor in a certain direction, what rule will it observe in rebounding? What is the angle called, which the ball makes in approaching the floor? What is the angle called, which it makes in leaving the floor? What is the difference between these angles?

Compound Motion.

Compound motion is that motion, which is produced by two or more forces, acting in different directions, on the same body, at the same time. This will be readily understood by a diagram.

Fig. 13.

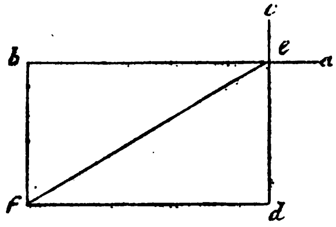


Suppose the ball *a*, fig. 13, to be moving with a certain velocity in the line *b c*, and suppose that at the instant when it came to the point *a*, it should be struck with an equal force in the direction of *d e*, as it cannot obey the direction of both these forces, it will take a course between them, and fly off in the direction of *f*.

The reason of this is plain. The first force would carry the ball from *b* to *c*; the second would carry it from *d* to *e*, and these two forces being equal, gives it a direction just half way between the two, and therefore it is sent towards *f*.

The line *a f*, is called the *diagonal of the square*, and results from the cross forces, *b* and *d* being equal to each other. If one of the moving forces is greater than the other, then the diagonal line will be lengthened in the direction of the greater force, and instead of being the diagonal of a square, it will become the diagonal of a parallelogram, or oblong square.

Fig. 14.



Suppose the force in the direction of *a b*, should drive the ball with twice the velocity of the cross force *c d*, fig. 14, then the ball would go twice as far from the line *c d*, as from the line *b a*, and *e f* would be the diagonal of a parallelogram whose length is double its breadth.

What is compound motion? Suppose a ball, moving with a certain force, to be struck crosswise, with the same force, in what direction will it move? Suppose it to be struck with half its former force, in what direction will it move?

Suppose a boat in crossing a river, is rowed forward at the rate of four miles an hour, and the current of the river is at the same rate, then the two cross forces will be equal, and the line of the boat will be the diagonal of a square, as in fig. 13. But if the current be four miles an hour, and the progress of the boat forward only two miles an hour, then the boat will go down stream twice as fast as she goes across the river, and her path will be the diagonal of a parallelogram, as in fig. 14, and therefore to make the boat pass directly across the stream, it must be rowed towards some point higher up the stream than the landing place; a fact well known to boatmen.

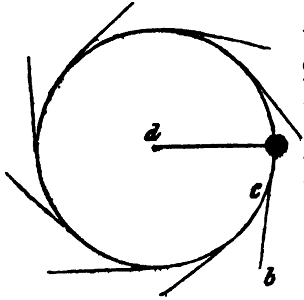
Circular Motion.

Circular motion, is the motion of a body in a ring, or circle, and is produced by the action of two forces. By one of these forces, the moving body tends to fly off in a straight line, while by the other it is drawn towards the centre, and thus it it made to revolve, or move round in a circle.

The force by which a body tends to go off in a straight line is called the *centrifugal force;* that which keeps it from flying away, and draws it towards the centre, is called the *centripetal force.*

Bodies moving in circles are constantly acted upon by these two forces. If the centrifugal force should cease, the moving body would no longer perform a circle, but would directly approach the centre of its own motion. If the centripetal force should cease, the body would instantly begin to move off in a straight line, this being, as we have explained, the direction which all bodies take when acted on by a single force.

Fig. 15.



This will be obvious by fig. 15. Suppose *a* to be a cannon ball, tied with a string to the centre of a slab of smooth marble, and suppose an attempt be made to push this ball with the hand in the direction of *b*; it is obvious that the string would prevent its going to that point; but would keep it in the circle. In this case, the string is the centripetal force.

What is the line *A F*, fig. 13, called? What is the line *E F*, fig. 14, called? How are there figures illustrated? What is circular motion? How is this motion produced? What is the centrifugal force?

Now suppose the ball to be kept revolving with rapidity, its velocity and weight will occasion its centrifugal force; and if the string were cut, when the ball was at the point *c*, for instance, this force would carry it off in the line towards *b*.

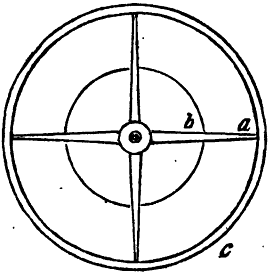
The greater the velocity with which a body moves round in a circle, the greater will be the force with which it will fly off in a right line.

Thus, when one wishes to sling a stone to the greatest distance, he makes it whirl round with the greatest possible rapidity, before he lets it go. Before the invention of other warlike instruments, soldiers threw stones in this manner with great force, and dreadful effects.

The line about which a body revolves, is called its *axis of motion*. The point round which it turns, or on which it rests, is called the *centre of motion*. In fig. 15, the point *d*, to which the string is fixed, is the centre of motion. In the spinning top, a line through the centre of the handle to the point on which it turns, is the axis of motion.

In the revolution of a wheel, that part which is at the greatest distance from the axis of motion, has the greatest velocity, and consequently, the greatest centrifugal force.

Fig. 16.



Suppose the wheel, fig. 16, to revolve a certain number of times in a minute, the velocity of the end of the arm, at the point *a*, would be as much greater than its middle at the point *b*, as its distance is greater from the axis of motion, because it moves in a larger circle, and consequently the centrifugal force of the rim *c*, would in like manner, be as its distance from the centre of motion.

Large wheels, which are designed to turn with great velocity, must, therefore, be made with corresponding strength,

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What is the centripetal force? Suppose the centrifugal force should cease, in what direction would the body move? Suppose the centripetal force should cease, where would the body go? Explain fig. 15. What constitutes the centrifugal force of a body moving round in a circle? How is this illustrated? What is the axis of motion? What is the centre of motion? Give illustrations. What part of a revolving wheel has the greatest centrifugal force? Why?

otherwise the centrifugal force will overcome the cohesive attraction, or the strength of the fastenings, in which case the wheel will fly in pieces. This sometimes happens to the large grindstones used in gun-factories, and the stone either flies away piece-meal, or breaks in the middle, to the great danger of the workmen.

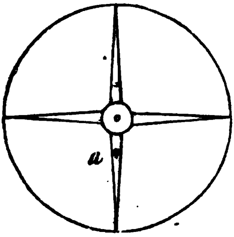
Were the diurnal velocity of the earth about seventeen times greater than it is, those parts at the greatest distance from its axis, would begin to fly off in straight lines, as the water does from a grindstone, when it is turned rapidly.

Centre of Gravity.

The *centre of gravity*, in any body or system of bodies, is that point upon which the body, or system of bodies, acted upon only by gravity, will balance itself in all positions.

The centre of gravity, in a wheel made entirely of wood, and of equal thickness, would be exactly in the middle, or in its ordinary centre of motion. But if one side of the wheel were made of iron, and the other part of wood, its centre of gravity would be changed to some point, aside from the centre of the wheel.

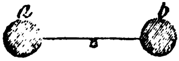
Fig. 17.



Thus, the centre of gravity in the wooden wheel, fig. 17, would be at the axis on which it turns; but were the arm *a*, of iron, its centre of motion and of gravity would no longer be the same, but while the centre of motion remained as before, the centre of gravity would fall to the point *a*. Thus the centre of motion and of gravity, though often at the same point, are not always so.

When the body is shaped irregularly, or there are two or more bodies connected, the centre of gravity is the point on which they will balance without falling.

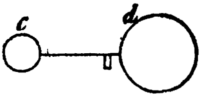
Fig. 18.



If the two balls *a* and *b*, fig. 18, weigh each four pounds, the centre of gravity will be a point on the bar equally distant from each.

Why must large wheels, turning with great velocity, be strongly made? What would be the consequence, were the velocity of the earth 17 times greater than it is? Where is the centre of gravity in a body? Where is the centre of gravity in a wheel, made of wood? If one side is made of wood, and the other of iron, where is this centre? Is the centre of motion and of gravity always the same?

Fig. 19.



But if one of the balls be heavier than the other, then the centre of gravity will, in proportion, approach the larger ball. Thus in fig. 19, if *c* weighs two pounds and *d* eight pounds, the centre of gravity will be four times the distance from *c* that it is from *d*.

In a body of equal thickness, as a board, or a slab of marble, but otherwise of an irregular shape, the centre of gravity may be found by suspending it, first from one point, and then from another, and marking by means of a plumb line the perpendicular ranges from the point of suspension. The centre of gravity will be the point where these two lines cross each other.

Thus, if the irregular shaped piece of board, fig. 20, be suspended by making a hole through it at the point *a*, and at the same point suspending the plumb line *c*, both board and line will hang in the position represented in the figure. Having marked this line across the board, let it be suspended again in the position of fig. 21, and the perpendicular line again marked. The point where these lines cross each other, is the centre of gravity, as seen by fig. 22.

Fig. 20.

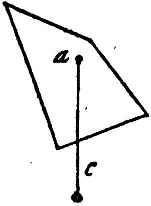


Fig. 21.

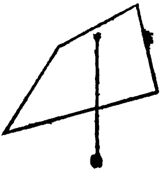
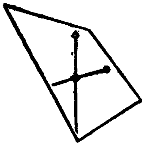


Fig. 22.



It is often of great consequence, in the concerns of life, that the subject of gravity should be well considered, since the strength of buildings, and of machinery, often depends chiefly on the gravitating point.

Common experience teaches, that a tall object, with a narrow base, or foundation, is easily overturned; but common experience does not teach the reason, for it is only by understanding principles, that practice improves experiment.

An upright object will fall to the ground when it leans so much that a perpendicular line from its centre of gravity falls beyond its base. A tall chimney, therefore, with a narrow

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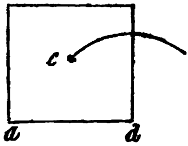
When two bodies are connected, as by a bar between them, where is the centre of gravity? In a board of irregular shape, by what method is the centre of gravity found?

foundation, such as are commonly built at the present day, will fall with a very slight inclination.

Now in falling, the centre of gravity passes through the part of a circle, the centre of which is at the extremity of the base on which the body stands. This will be comprehended by fig. 23.

Fig. 23.

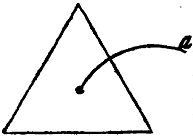


Suppose the figure to be a block of marble, which is to be turned over, by lifting at the corner *a*, the corner *d* would be the centre of its motion, or the point on which it would turn. The centre of gravity, *c*, would, therefore, describe the part of a circle, of which the corner, *d*, is the centre.

It will be obvious, after a little consideration, that the greatest difficulty we should find in turning over a square block of marble, would be, in first raising up the centre of gravity, for the resistance will constantly become less, in proportion as the point approaches a perpendicular line over the corner *d*, which, having passed, it will fall by its own gravity.

The difficulty of turning over a body of a particular form, will be more strikingly illustrated by the figure of a triangle, or low pyramid.

Fig. 24.



In fig. 24, the centre of gravity is so low, and the base so broad, that in turning it over, a great proportion of its whole weight must be raised. Hence we see the firmness of the pyramid in theory, and experience proves its truth; for buildings are found to withstand the effects of time, and the commotions of earthquakes, in proportion as they approach this figure.

The most ancient monuments of the art of building, now standing, the pyramids of Egypt, are of this form.

When a ball is rolled on a horizontal plane, the centre of gravity is not raised, but moves in a straight line parallel to

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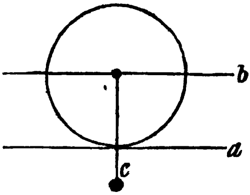
In what direction must the centre of gravity be from the outside of the base, before the object will fall? In falling, the centre of gravity passes through part of a circle; where is the centre of this circle? In turning over a body, why does the force required constantly become less and less? Why is there less force required to overturn a cube, or square, than a pyramid of the same weight? When a ball is rolled on a horizontal plane, in what direction does the centre of gravity move?

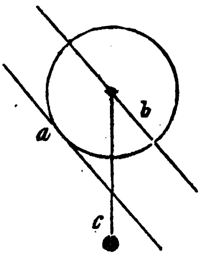
the surface of the plane on which it rolls, and is consequently always directly over its centre of motion.

Fig. 25.



Suppose, fig. 25, *a* is the plane on which the ball moves, *b* the line on which the centre of gravity moves, and *c* a plumb line, showing that the centre of gravity must always be exactly over the centre of motion, when the ball moves on a horizontal plane —then we shall see the reason why a ball moving on such a plane, will rest with equal firmness in any position, and why so little force is required to set it in motion. For in no other figure does the centre of gravity describe a horizontal line over that of motion, in whatever direction the body is moved.

Fig. 26.



If the plane is inclined downwards, the ball is instantly thrown into motion because the centre of gravity then falls forward of that of motion, or the point on which the ball rests.

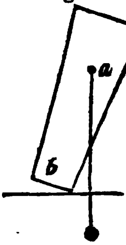
This is explained by fig. 26, where *a* is the point on which the ball rests, or the centre of motion, *c* the perpendicular line from the centre of gravity as shown by the plumb weight *c*.

If the plane is inclined upward, force is required to move the ball in that direction, because the centre of gravity then falls behind that of motion, and therefore the centre of gravity has to be constantly lifted. This is also shown by fig. 26, only considering the ball to be moving up the inclined plane, instead of down it.

From these principles, it will be readily understood, why so much force is required to roll a heavy body, as a hogshead of sugar, for instance, up an inclined plane. The centre of gravity falling behind that of motion, the weight is constantly acting against the force employed to raise the body.

Explain fig. 25. Why does a ball on a horizontal plane rest equally well in all positions? Why does it move with little force? If the plane is inclined downwards, why does the ball roll in that direction? Why is force required to move a ball up an inclined plane?

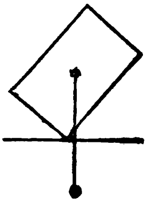
Fig. 27.



From what has been stated, it will be understood, that the danger that a body will fall, is in proportion to the narrowness of its base, compared with the height of the centre of gravity above the base.

Thus a tall body, shaped like fig. 27, will fall, if it leans but very slightly, for the centre of gravity being far above the base, at *a*, is brought over the centre of motion, *b*, with little inclination, as shown by the plumb line. Whereas a body shaped like fig. 28, will not fall, until it leans much more, as again shown by the direction of the plumb line.

Fig. 28.



We may learn from these comparisons, that it is more dangerous to ride in a high carriage than in a low one, in proportion to the elevation of the vehicle, and the nearness of the wheels to each other, or in proportion to the narrowness of the base, and the height of the centre of gravity. A load of hay upsets where the road raises one wheel but little higher than the other, because it is high, and broader on the top than the distance of the wheels from each other; while a load of stone is very rarely turned over, because the centre of gravity is near the earth, and its weight between the wheels, instead of being far above them.

In man the centre of gravity is between the hips, and hence, were his feet tied together, and his arms tied to his sides, a very slight inclination of his body would carry the perpendicular of his centre of gravity beyond the base, and he would fall. But when his limbs are free to move, he widens his base, and changes the centre of gravity at pleasure, by throwing out his arms, as circumstances require.

When a man runs, he inclines forward, so that the centre of gravity may hang before his base, and in this position, he is obliged to keep his feet constantly advancing, otherwise he would fall forward.

What is the danger that a body will fall proportioned to? Why is a body, shaped like fig. 27, more easily thrown down, than one shaped like fig. 28? Hence, in riding in a carriage, how is the danger of upsetting proportioned? Where is the centre of a man's gravity? Why will a man fall with a slight inclination, when his feet and arms are tied?

A man standing on one foot, cannot throw his body forward without at the same time throwing his other foot backward, in order to keep his centre of gravity within the base.

A man, therefore, standing with his heels against a perpendicular wall, cannot stoop forward without falling, because the wall prevents his throwing any part of his body backward. A person, little versed in such things, agreed to pay a certain sum of money for an opportunity of possessing himself of double the sum, by taking it from the floor with his heels against the wall. The man, of course, lost his money, for in such a posture, one can hardly reach lower than his own knee.

The base, on which a man is supported, in walking or standing, is his feet, and the space between them. By turning the toes out, this base is made broader, without taking much from its length, and hence persons who turn their toes outward, not only walk more firmly, but more gracefully, than those who turn them inward.

In consequence of the upright position of man, he is constantly obliged to employ some exertion to keep his balance. This seems to be the reason why children learn to walk with so much difficulty, for after they have strength to stand, it requires considerable experience, so to balance the body, as to set one foot before the other without falling.

By experience in the art of balancing, or of keeping the centre of gravity in a line over the base, men sometimes perform things, that, at first sight, appear altogether beyond human power, such as dining with the table and chair standing on a single rope, dancing on a wire, &c

No form under which matter exists, escapes the general law of gravity, and hence vegetables, as well as animals are formed with reference to the position of this centre, in respect to the base.

It is interesting, in reference to this circumstance, to observe how exactly the tall trees of the forest conform to this law.

The pine, which grows a hundred feet high, shoots up with as much exactness, with respect to keeping its centre of gravity within the base, as though it had been directed by the

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Why cannot one who stands with his heels against a wall stoop forward? Why does a person walk most firmly, who turns his toes outward? Why does not a child walk as soon as he can stand? In what does the art of balancing, or walking on a rope, consist? What is observed in the growth of the trees of the forest, in respect to the laws of gravity?

plumb line of a master builder. Its limbs towards the top are sent off in conformity to the same law; each one growing in respect to the other, so as to preserve a due balance between the whole.

It may be observed, also, that where many trees grow near each other, as in thick forests, and consequently where the wind can have but little effect on each, that they always grow taller than when standing alone on the plain. The roots of such trees are also smaller, and do not strike so deep as those of trees standing alone. A tall pine, in the midst of the forest, would be thrown to the ground by the first blast of wind, were all those around it cut away.

Thus, the trees of the forest, not only grow so as to preserve their centres of gravity; but actually conform, in a certain sense, to their situation.

Centre of Inertia.

It will be remembered that *inertia* is one of the inherent, or essential properties of matter, and that it is in consequence of this property, when bodies are at rest, that they never move without the application of force, and when once in motion, that they never cease moving without some external cause.

Now inertia, though, like gravity, it resides equally in every particle of matter, must have, like gravity, a centre in each particular body, and this centre is the same with that of gravity.

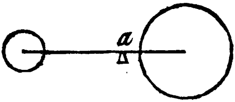
In a bar of iron, six feet long, and two inches square, the centre of gravity is just three feet from each end, or exactly in the middle. If, therefore, the bar is supported at this point, it will balance equally, and because there are equal weights on both ends, it will not fall. This, therefore, is the centre of gravity.

Now suppose the bar should be raised by raising up the centre of gravity, then the inertia of all its parts would be overcome equally with that of the middle. The centre of gravity is, therefore, the centre of inertia.

The centre of inertia, being that point, which, being lifted, the whole body is raised, is not, therefore, always at the centre of the body.

What effect does inertia have on bodies at rest? What effect does it have on bodies in motion? Is the centre of inertia, and that of gravity, the same? Where is the centre of inertia in a body, or a system of bodies?

Fig. 29.



Thus, suppose the same bar of iron, whose inertia was overcome by raising the centre, to have balls of different weights attached to its ends; then the centre of inertia would no longer remain in the middle of the bar, but would be changed to the point *a*, fig. 29, so that to lift the whole, this point must be raised, instead of the middle, as before.

Equilibrium.

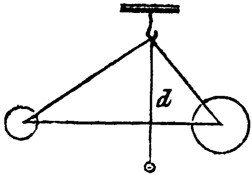
When two forces counteract, or balance each other, they are said to be in *equilibrium.*

It is not necessary for this purpose, that the weights opposed to each other should be equally heavy, for we have just seen that a small weight placed at a distance from the centre of inertia, will balance a large one placed near it. To produce equilibrium, it is only necessary, that the weights on each side of the support should mutually counteract each other, or if set in motion, that their momenta should be equal.

A pair of scales are in equilibrium, when the beam is in a horizontal position.

To produce equilibrium in solid bodies, therefore, it is only necessary to support the centre of inertia, or gravity.

Fig. 30.



If a body, or several bodies, connected, be suspended by a string, as in fig. 30, the point of support is always in a perpendicular line above the centre of inertia. The plumb line *d*, cuts the bar connecting the two balls at this point. Were the two weights in this figure equal, it is evident that the hook, or point of support, must be in the middle of the string, to preserve the horizontal position.

When a man stands on his right foot, he keeps himself in equilibrium, by leaning to the right, so as to bring his centre of gravity in a perpendicular line over the foot on which he stands.

Why is the point of inertia changed, by fixing different weights to the ends of the iron bar? What is meant by equilibrium? To produce equilibrium, must the weights be equal? When is a pair of scales in equilibrium When a body is suspended by a string, where must the support be with respect to the point of inertia?

Curvilinear, or bent Motion.

We have seen that a single force acting on a body, drives it straight forward, and that two forces acting crosswise, drive it midway between the two, or give it a diagonal direction.

Curvilinear motion differs from both these, the direction of the body being neither straight forward, nor diagonal, but through a line which is curved.

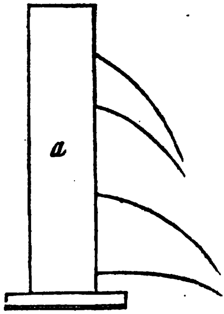
This kind of motion may be in any direction, but when it is produced in part by gravity, its direction is always towards the earth.

A stream of water from an aperture in the side of a vessel, as it falls towards the ground, is an example of a curved line, and a body passing through such a line, is said to have *curvilinear* motion. Any body projected forward, as a cannon ball or rocket, falls to the earth in a curved line.

It is the action of gravity across the course of the stream, or the path of the ball, that bends it downwards, and makes it form a curve. This motion is therefore the result of two forces, that of projection, and that of gravity.

The shape of the curve, will depend on the velocity of the stream or ball. When the pressure of the water is great, the stream, near the vessel, is nearly horizontal, because its velocity is in proportion to the pressure. When a ball first leaves the cannon, it describes but a slight curve, because its projectile velocity is then greatest.

Fig. 31.



The curves prescribed by jets of water, under different degrees of pressure, are readily illustrated by tapping a tall vessel in several places, one above the other.

Suppose fig. 31 to be such a vessel, filled with water and pierced as represented. The streams will form curves differing from each other, as seen in the figure. Where the projectile force is greatest, as from the lower orifice, the stream reaches the ground at the greatest distance from the vessel, this distance decreasing, as the pressure

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What is meant by curvilinear motion? What are examples of this kind of motion? What two forces produce this motion? On what does the shape of the curve depend? How are the curves described by jets of water illustrated?

becomes less towards the top of the vessel. The action of gravity being always the same, the shape of the curve described, as just stated, must depend on the velocity of the moving body; but whether the projectile force be great or small, the moving body, if thrown horizontally, will reach the ground from the same height in the same time.

This, at first thought, would seem improbable, for without consideration, most persons would assert, very positively, that if two cannon were fired from the same spot, at the same instant, and in the same direction, one of the balls falling half a mile, and the other a mile distant, that the ball which went to the greatest distance, would take the most time in performing its journey.

But it must be remembered that the projectile force does not in the least interfere with the force of gravity. A ball flying horizontally at the rate of a thousand feet per second, is attracted downwards with precisely the same force as one, flying only a hundred feet per second, and must therefore descend the same distance in the same time.

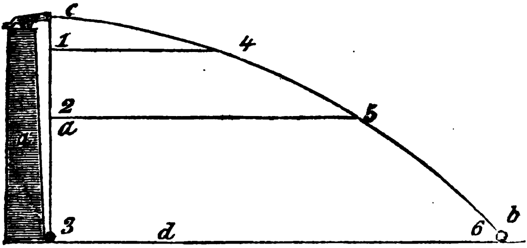
The distance to which a ball will go, depends on the force of impulse given it the first instant, and consequently on its projectile velocity. If it moves slowly, the distance will be short—if more rapidly, the space passed over will be greater. It makes no difference, then, in respect to the descent of the ball, whether its projectile motion be fast, or slow, or whether it moves forward at all.

This is demonstrated by experiment. Suppose a cannon to be loaded with a ball, and placed on the top of a tower, at such a height from the ground, that it would take just three seconds for a cannon ball to descend from it to the ground, if let fall perpendicularly. Now suppose the cannon to be fired in an exact horizontal direction, and at the same instant, the ball to be dropped towards the ground. They will both reach the ground at the same instant, provided its surface be a horizontal plane from the foot of the tower to the place where the projected ball strikes.

What difference is there in respect to the time taken by a body to reach the ground, whether the curve be great or small? Why do bodies forming different curves from the same height, reach the ground at the same time? Suppose two balls, one flying at the rate of a thousand, and the other at the rate of a hundred feet per second, which would descend most during the second? Does it make any difference in respect to the descent of the ball, whether it has a projectile motion or not? Suppose, then, one ball be fired from a cannon, and another let fall from the same height at the same instant, would they both reach the ground at the same time?

This will be made plain by fig. 32, where *a* is the perpendicular line of the descending ball, *c b* the curvilinear path of that projected from the cannon, and *d*, the horizontal line from the foot of the tower.

Fig. 32.



The reason why the two balls will reach the ground at the same time, is easily comprehended.

During the first second, suppose that the ball which is dropped, reaches 1; during the next second it falls to 2, and at the end of the third second it strikes the ground. Meantime, the ball shot from the cannon is projected forward with such velocity as to reach 4 in the same time that the other is falling to 1. But the projected ball falls downward exactly as fast as the other, for it meets the line 1, 4, which is parallel to the horizon at the same instant. During the next second, the projected ball reaches 5, while the other arrives at 2; and here again they have both descended through the same downward space, as is seen by the line 2, 5, which is parallel with the other. During the third second, the ball from the cannon will have nearly spent its projectile force, and therefore, its motion downward will be greater, while its motion forward will be less than before. The reason of this will be obvious, when it is considered, that in respect to gravity, both balls follow exactly the same law, and fall through equal spaces in equal times. Therefore as the falling ball descends through the greatest space during the last second, so that from the cannon, having now a less projectile motion, its downward motion is more direct, and, like all falling bodies, its velocity is increased as it approaches the earth.

Explain fig. 32, showing the reason why the two balls will reach the ground at the same time. Why does the ball approach the earth more rapidly in the last part of the curve, than in the first part?

From these principles it may be inferred, that the horizontal motion of a body through the air, does not in the least interfere with its gravitating motion towards the earth, and therefore that a rifle ball, or any other body projected forward horizontally, will reach the ground in exactly the same period of time, as one that is let fall perpendicularly from the same height.

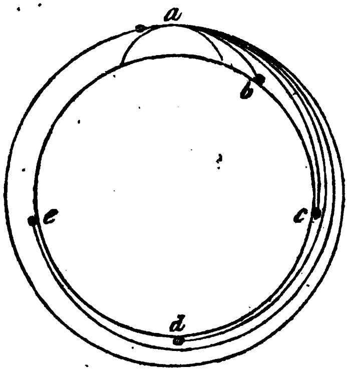
The two forces acting on bodies which fall through curved lines, are the same as the centrifugal and centripetal forces, already explained; the centrifugal, in case of the ball, being caused by the powder—the centripetal, being the action of gravity.

Now, it is obvious, that the space through which a cannon ball, or any other body, can be thrown, depends on the velocity with which it is projected, for the attraction of gravitation and the resistance of the air acting perpetually, the *time* which a projectile can be kept in motion, through the air, is only a few moments.

If, however, the projectile be thrown from an elevated situation, it is plain that it would strike at a greater distance than if thrown on a level, because it would remain longer in the air. Every one knows that he can throw a stone to a greater distance, when standing on a steep hill, than when standing on the plain below.

Bonaparte, it is said, by elevating the range of his shot, bombarded Cadiz from the distance of five miles. Perhaps, then, from a high mountain, a cannon ball might be thrown to the distance of six or seven miles.

Fig. 33.



Suppose the circle, fig. 33, to be the earth, and *a* a high mountain on its surface. Suppose that this mountain reaches above the atmosphere, or is fifty miles high, then a cannon ball might perhaps reach from *a* to *b*, a distance of eighty or a hundred miles, because the resistance of the atmosphere being out of the calculation, it would have nothing to contend with, except the attraction of

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What is the force called which throws a ball forward?

gravitation. If, then, one degree of force, or velocity, would send it to *b*, another would send it to *c*: and if the force was increased three times, it would fall at *d*, and if four times, it would pass to *e*. If now we suppose the force to be about ten times greater than that with which a cannon ball is projected, it would not fall to the earth at any of these points, but would continue its motion, until it again came to the point *a*, the place from which it was first projected. It would now be in equilibrium, the centrifugal force being just equal to that of gravity, and therefore it would perform another, and another revolution, and so continue to revolve around the earth perpetually.

The reason why the force of gravity will not ultimately bring it to the earth, is, that during the first revolution, the effect of this force is just equal to that exerted in any other revolution, but neither more nor less; and, therefore, if the centrifugal force was sufficient to overcome this attraction during one revolution, it would also overcome it during the next. It is supposed, also, that nothing tends to affect the projectile force except that of gravity, and the force of this attraction would be no greater during any other revolution, than during the first.

In other words, the centrifugal and centripetal forces are supposed to be exactly equal, and to mutually balance each other; in which case, the ball would be, as it were, suspended between them. As long, therefore, as these two forces continued to act with the same power, the ball would no more deviate from its path, than a pair of scales would lose their balance without more weight on one side than on the other.

It is these two forces which retain the heavenly bodies in their orbits, and in the case we have supposed, our cannon ball would become a little satellite, moving perpetually round the earth.

Resultant Motion.

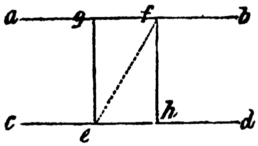
Suppose two men to be sailing in two boats, each at the

What is that called, which brings it to the ground? On what does the distance to which a projected body may be thrown depend? Why does the distance depend upon the velocity? Explain fig. 33. Suppose the velocity of a cannon ball shot from a mountain 50 miles high, to be ten times its usual rate, where would it stop? When would this ball be in equilibrium? Why would not the force of gravity ultimately bring the ball to the earth? After the first revolution, if the two forces continued the same, would not the motion of the ball be perpetual?

rate of four miles an hour, at a short distance opposite t other, and suppose as they are sailing along in this manner one of the men throws the other an apple. In respect to the boats, the apple would pass directly across, from one to the other, that is, its line of direction would be perpendicular to the sides of the boats. But its actual line through the air, would be oblique, or diagonal, in respect to the sides of the boats, because in passing from boat to boat, it is impelled by two forces, viz. the force of the motion of the boat forward, and the force by which it is thrown by the hand across this motion.

This diagonal motion of the apple is called the *resultant*, or the resulting motion, because it is the effect, or result, of two motions, resolved into one. Perhaps this will be more clear by fig. 34, where *a b*, and *c d*, are supposed to be the sides of the two boats, and the line *e f*, that of the apple. Now the apple, when thrown, has a motion with the boat at the rate of four miles an hour, from *c* towards *d*, and this motion is supposed to continue just as though it had remained in the boat. Had it remained in the boat during the time it was passing from *e* to *f*, it would have passed from *e* to *h*. But we suppose it to have been thrown at the rate of eight miles an hour in the direction towards *g*, and if the boats are moving south, and the apple thrown towards the east, it would pass, in the same time, twice as far towards the east as it did towards the south. Therefore, in respect to the boats, the apple would pass in a perpendicular line from the side of one to that of the other, because they are both in motion, but in respect to one perpendicular line drawn from the point where the apple was thrown, and a parallel line with this, drawn from the point where it strikes the other boat, the line of the apple would be oblique. This will be clear, when we consider that when the apple is thrown, the boats are at the points *e* and *g*, and that when it strikes, they are at *h* and *f*, these two points being opposite to each other.

Fig. 34.



Suppose two boats sailing at the same rate and in the same direction, i an apple be tossed from one to the other, what will be its direction in respect to the boats? What would be its line through the air, in respect to the boats? What is this kind of motion called? Why is it called resultant motion? Explain fig. 34.

The line *e, f*, through which the apple is thrown, is called the diagonal of a parallelogram, as already explained under compound motion.

On the above principle, if two ships, during a battle, are sailing before the wind at equal rates, the aim of the gunners will be exactly the same as though they stood still; whereas if the gunner fires from a ship standing still, at another under sail, he takes his aim forward of the mark he intends to hit, because the ship would pass a little forward while the ball is going to her. And so, on the contrary, if a ship in motion fires at another standing still, the aim must be behind the mark, because, as the motion of the ball partakes of that of the ship, it will strike forward of the point aimed at.

For the same reason, if a ball be dropped from the topmast of a ship under sail, it partakes of the motion of the ship forward, and will fall in a line with the mast, and strike the same point on the deck, as though the ship stood still.

If a man upon the full run drops a bullet before him from the height of his head, he cannot run so fast as to overtake it before it reaches the ground.

It is on this principle, that if a cannon ball be shot up vertically from the earth, it will fall back to the same point; for although the earth moves forward while the ball is in the air, yet as it carries this motion with it, so the ball moves forward also, in an equal degree, and therefore comes down at the same place.

Ignorance of these laws induced the story-making sailor to tell his comrades, that he once sailed in a ship which went so fast, that when a man fell from the mast-head, the ship sailed away and left the poor fellow to strike into the water behind her.

Pendulum.

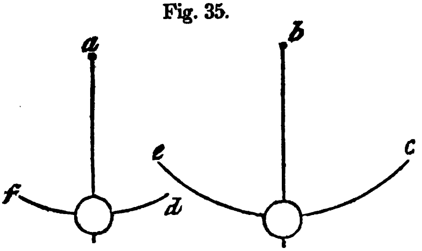
A *pendulum* is a heavy body, such as a piece of brass, or lead, suspended by a wire or cord, so as to swing backwards and forwards.

Why would the line of the apple be actually perpendicular in respect to the boats, but oblique in respect to parallel lines drawn from where it was thrown, and where it struck? How is this further illustrated? When the ships are in equal motion, where does the gunner take his aim? Why does he aim forward of the mark, when the other ship is in motion? If a ship in motion fires at one standing still, where must be the aim? Why, in this case, must the aim be behind the mark? What other illustrations are given of resultant motion? What is a pendulum?

When a pendulum swings, it is said to *vibrate;* and that part of a circle through which it vibrates, is called its *arc.*

The times of the vibration of a pendulum are very nearly equal, whether it pass through a greater or less part of its arc.

Fig. 35.



Suppose *a* and *b*, fig. 35, to be two pendulums of equal length, and suppose the weights of each are carried, the one to *c*, and the other to *d*, and both let fall at the same instant; their vibrations would be equal in respect to time, the one passing through its arc from *c* to *e*, and so back again in the same time that the other passes from *d* to *f*, and back again.

The reason of this appears to be, that when the pendulum is raised high, the action of gravity draws it more directly downwards, and it therefore acquires, in falling, a greater comparative velocity than is proportioned to the trifling difference of height.

In the common clock, the pendulum is connected with wheel work, to regulate the motions of the hands, and with weights by which the whole is moved. The vibrations of the pendulum are numbered by a wheel having sixty teeth, which revolves once in a minute. Each tooth, therefore, answers to one swing of the pendulum, and the wheel moves forward one tooth in a second. Thus the second hand revolves once in every sixty beats of the pendulum, and as these beats are seconds, it goes round once in a minute. By the pendulum, the whole machine is regulated, for the clock goes faster, or slower, according to its number of vibrations in a given time. The number of vibrations which a pendulum makes in a given time, depends upon its length, because a long pendulum does not perform its journey to and from the corresponding points of its arc so soon as a short one.

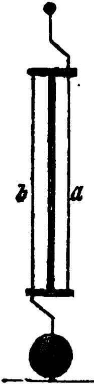
What is meant by the vibration of a pendulum? What is that part of a circle called, through which it swings? Why does a pendulum vibrate in equal time, whether it goes through a small or large part of its arc? Describe the common clock. How many vibrations has the pendulum in a minute? On what depends the number of vibrations which a pendulum makes in a given time?

As the motion of the clock is regulated entirely by the pendulum, and as the number of vibrations are as its length, the least variation in this respect will alter its rate of going. To beat seconds, its length must be about 39 inches. In the common clock, the length is regulated by a screw, which raises and lowers the weight. But as the rod to which the weight is attached, is subject to variations of length in consequence of the change of the seasons, being contracted by cold, and lengthened by heat, the common clock goes faster in winter than in summer.

Various means have been contrived to counteract the effects of these changes, so that the pendulums may continue the same length the whole year. Among inventions for this purpose, the *gridiron* pendulum is considered the best. It is so called, because it consists of several rods of metal connected together at each end.

The principle on which this pendulum is constructed, is derived from the fact, that some metals dilate more by the same degrees of heat than others. Thus brass will dilate twice as much by heat, and consequently contract twice as much by cold, as steel. If then these differences could be made to counteract each other mutually, given points at each end of a system of such rods would remain stationary the year round, and thus the clock would go at the same rate in all climates, and during all seasons.

Fig. 36.



This important object is accomplished by the following means.

Suppose the middle rod, fig. 36, to be made of brass, and the two outside ones of steel, all of the same length. Let the brass rod be firmly fixed to the cross pieces at each end. Let the steel rod *a*, be fixed to the lower cross piece, and *b*, to the upper cross piece. The rod *a*, at its upper end passes through the cross piece, and in like manner, *b* passes through the lower one. This is done to prevent these small rods from playing backwards and forwards as the pendulum swings.

Now as the middle rod is lengthened by the heat twice as much as the outside ones, and the outside rods together are twice as long as the middle one, the actual length of the pendulum can neither be

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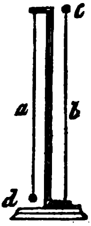
What is the medium length of a pendulum beating seconds? Why does a common clock go faster in winter than in summer?

increased nor diminished by the variations of temperature.

Fig. 37.



To make this still plainer, suppose the lower cross piece, fig. 37, to be standing on a table, so that it could not be lengthened downwards, and suppose, by the heat of summer, the middle rod of brass should increase one inch in length. This would elevate the upper cross piece an inch, but at the same time the steel rod *a*, swells half an inch, and the steel rod *b*, half an inch, therefore, the two points *c* and *d*, would remain exactly at the same distance from each other.

As it is the force of gravity which draws the weight of the pendulum from the highest point of its arc downwards, and as this force increases, or diminishes, as bodies approach towards the centre of the earth, or recede from it, so the pendulum will vibrate faster, or slower, in proportion as this attraction is stronger or weaker.

Now, it is found that the earth at the equator rises higher from its centre, than it does at the poles, for towards the poles it is flattened. The pendulum, therefore, being more strongly attracted at the poles than at the equator, vibrates faster. For this reason, a clock that would keep exact time at the equator, would gain time at the poles, for the rate at which a clock goes, depends on the number of vibrations its pendulum makes. Therefore, pendulums, in order to beat seconds, must be shorter at the equator and longer at the poles.

For the same reason, a clock which keeps exact time at the foot of a high mountain would move slower on its top.

There is a short pendulum, used by musicians for marking time, which may be made to vibrate fast or slow, as occasion requires. This little instrument is called a *metronome*, and besides the pendulum, consists of several wheels, and a spiral spring, by which the whole is moved. This pendulum is only

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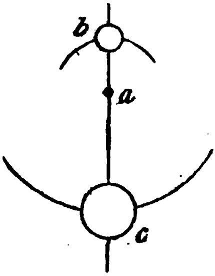
What is necessary in respect to the pendulum, to make the clock go true the year round? What is the principle on which the gridiron pendulum is constructed? What are the metals of which this instrument is made? Explain fig. 36, and give the reason why the length of the pendulum will not change by the variations of temperature. Explain fig. 37. What is the downward force which makes the pendulum vibrate? Explain the reason why the same clock would go faster at the poles and slower at the equator. How can a clock which goes true at the equator be made to go true at the poles?

ten or twelve inches long, and instead of being suspended by the end, like other pendulums, the rod is prolonged above the point of suspension, and there is a ball placed near the upper, as well as at the lower extremity.

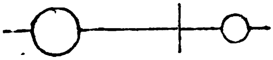
Fig. 38.



This arrangement will be understood by fig. 38, where *a* is the axis of suspension, *b* the upper ball, and *c* the lower one. Now when this pendulum vibrates from the point *a*, the upper ball constantly retards the motion of the lower one, by in part counterbalancing its weight, and thus preventing its full velocity downwards.

Perhaps this will be more apparent, by placing the pendulum, fig. 39, for a moment on its side, and across a bar, at the point of suspension. In this position, it will be seen, that the little ball would prevent the large one from falling with its full weight, since, were it moved to a certain distance from the point of suspension, it would balance the large one, so that it would not descend at all. It is plain, therefore, that the comparative velocity of the large ball, will be in proportion as the small one is moved to a greater or less distance from the point of suspension. The metronome is so constructed, the little ball being made to move up and down on the rod, at pleasure, and thus its vibrations are made to beat the time of a quick, or slow tune, as occasion requires.

Fig. 39.



By this arrangement, the instrument is made to vibrate every two seconds, or every half, or quarter of a second, at pleasure.

MECHANICS.

Mechanics is a science which investigates the laws and effects of force and motion.

Will a clock keep equal time at the foot, and on the top of a high mountain? Why will it not? What is the metronome? How does this pendulum differ from common pendulums? How does the upper ball retard the motion of the lower one? How is the metronome made to go faster or slower at pleasure? What is mechanics?

The practical object of this science is, to teach the best modes of overcoming resistances by means of mechanical powers, and to apply motion to useful purposes, by means of machinery.

A *machine* is any instrument by which power, motion, or velocity, is applied, or regulated.

A machine may be very simple, or exceedingly complex. Thus, a pin is a machine for fastening clothes, and a steam engine is a machine for propelling mills and boats.

As machines are constructed for a vast variety of purposes, their forms, powers, and kinds of movement, must depend on their intended uses.

Several considerations ought to precede the actual construction of a new or untried machine; for if it does not answer the purpose intended, it is commonly a total loss to the builder.

Many a man, on attempting to apply an old principle to a new purpose, or to invent a new machine for an old purpose, has been sorely disappointed, having found, when too late, that his time and money had been thrown away, for want of proper reflection, or requisite knowledge.

If a man, for instance, thinks of constructing a machine for raising a ship, he ought to take into consideration the *inertia*, or *weight*, to be moved—the *force* to be applied—the *strength* of the materials, and the *space*, or situation, he has to work in. For, if the force applied, or the strength of the materials, be insufficient, his machine is obviously useless; and if the force and strength be ample, but the space be wanting, the same result must follow.

If he intends his machine for twisting the fibres of flexible substances into threads, he may find no difficulty in respect to power, strength of materials, or space to work in, but if the *velocity*, *direction*, and kind of motion he obtains, be not applicable to the work intended, he still loses his labour.

Thousands of machines have been constructed, which, so far as regarded the skill of the workmen, the ingenuity of the contriver, and the construction of the individual parts, were models of art and beauty; and, so far as could be seen without trial, admirably adapted to the intended purpose. But on putting them to actual use, it has too often been found, that their only imperfection consisted in a stubborn refusal to do any part of the work intended.

What is the object of this science? What is a machine? Mention one of the most simple, and one of the most complex of machines.

Now, a thorough knowledge of the laws of motion, and the principles of mechanics, would, in many instances at least, have prevented all this loss of labour and money, and spared him so much vexation and chagrin, by showing the projector that his machine would not answer the intended purpose.

The importance of this kind of knowledge is therefore obvious, and it is hoped will become more so as we proceed.

In mechanics, as well as in other sciences, there are words which must be explained, either because they are common words used in a peculiar sense, or because they are terms of art, not in common use. All technical terms will be as much as possible avoided, but still there are a few, which it is necessary here to explain.

Force is the means by which bodies are set in motion, kept in motion, and, when moving, are brought to rest. The force of gunpowder sets the ball in motion, and keeps it moving, until the force of resisting air, and the force of gravity, bring it to rest.

Power is the means by which the machine is moved, and the force gained. Thus we have horse power, water power, and the power of weights.

Weight is the resistance, or the thing to be moved by the force of the power. Thus, the stone is the weight to be moved by the force of the lever, or bar.

Fulcrum, or prop, is the point or part on which a thing is supported, and about which it has more or less motion. In raising a stone, the thing on which the lever rests, is the fulcrum.

In mechanics, there are a few simple machines, called the *mechanical powers*, and however mixed, or complex, a combination of machinery may be, it consists only of these few individual powers.

We shall not here burthen the memory of the pupil with the names of these powers, of the nature of which he is at present supposed to know nothing, but shall explain the action and use of each in its turn, and then sum up the whole for his accommodation.

What is meant by force, in mechanics? What is meant by power? What is understood by weight? What is the fulcrum? Are the mechanical powers numerous, or only few in number?

The Lever.

Any rod, or bar, which is used in raising a weight, or surmounting a resistance, by being placed on a fulcrum, or prop, becomes a lever.

This machine is the most simple of all the mechanical powers, and is therefore in universal use.

Fig. 40.

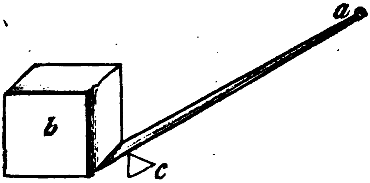


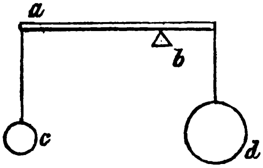
Fig. 40 represents a straight lever, or *hand spike*, called also a *crow-bar*, which is commonly used in raising and moving stone and other heavy bodies. The block *b* is the *weight*, or resistance, *a* is the *lever*, and *c*, the *fulcrum*.

The *power* is the hand, or weight of a man applied at *a*, to depress that end of the lever, and thus to raise the weight.

It will be observed, that by this arrangement, the application of a small power may be used to overcome a great resistance.

The force to be obtained by the lever, depends on its length, together with the power applied, and the distance of the weight and power from the fulcrum.

Fig. 41.

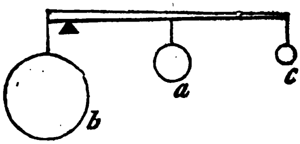


Suppose, fig. 41, that *a* is the lever, *b* the fulcrum, *d* the weight to be raised, and *c* the power. Let *d* be considered three times as heavy as *c*, and the fulcrum three times as far from *c* as it is from *d;* then the weight and power will exactly balance each other. Thus, if the bar be four feet long, and the fulcrum three feet from the end, then three pounds on the long arm, will weigh just as much as nine pounds on the short arm, and these proportions will be found the same in all cases.

What is a lever? What is the simplest of all mechanical powers? Explain fig. 40. Which is the weight? Where is the fulcrum? Where is the power applied? What is the power in this case? On what does the force to be obtained by the lever depend? Suppose a lever 4 feet long, and the fulcrum one foot from the end, what number of pounds will balance each other at the ends?

When two weights balance each other, the fulcrum is always at the centre of gravity between them, and therefore, to make a small weight raise a large one, the fulcrum must be placed as near as possible to the large one, since the greater the distance *from the fulcrum the small weight* or power is placed, the greater will be its force.

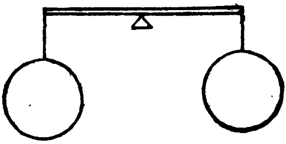
Fig. 42.



Suppose the weight *b*, fig. 42, to be sixteen pounds, and suppose the fulcrum to be placed so near it, as to be raised by the power *a*, of four pounds, hanging equally distant from the fulcrum and the end of the lever. If now the power *a*, be removed, and another of two pounds, *c*, be placed at the end of the lever, its force will be just equal to *a*, placed at the middle of the lever.

But let the fulcrum be moved along to the middle of the lever, with the weight of sixteen pounds still suspended to it, it would then take another weight of sixteen pounds, instead of two pounds, to balance it, fig. 43.

Fig. 43.



Thus the power which would balance 16 pounds, when the fulcrum is in one place, must be exchanged for another power weighing 8 times as much, when the fulcrum is in another place.

From these investigations, we may draw the following general truth, or proposition, concerning the lever: "*That the force of the lever increases in proportion to the distance of the power from the fulcrum, and diminishes in proportion as the distance of the weight from the fulcrum increases.*"

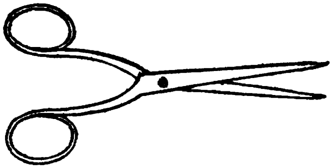
From this proposition may be drawn the following rule, by which the exact proportions between the weight, or resistance, and the power, may be found. *Multiply the weight by its*

When weights balance each other, at what point between them must the fulcrum be? Suppose a weight of 16 pounds on the short arm of a lever is counterbalanced by 4 pounds in the middle of the long arm, what power would balance this weight at the end of the lever? Suppose the fulcrum to be moved to the middle of the lever, what power would then be equal to the 16 pounds? What is the general proposition drawn from these results?

distance from the fulcrum; then multiply the power by its distance from the same point, and if the products are equal, the weight and the power will balance each other.

Suppose a weight of 100 pounds on the short arm of a lever, 8 inches from the fulcrum, then another weight, or power, of 8 pounds, would be equal to this, at the distance of 100 inches from the fulcrum; because 8 multiplied by 100 is equal to 800; and 100 multiplied by 8 is equal to 800, and thus they would mutually counteract each other.

Fig. 44.

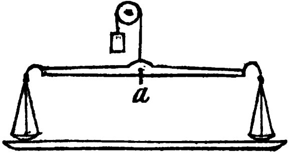


Many instruments in common use are on the principle of this kind of lever. Scissors, fig. 44, consist of two levers, the rivet being the fulcrum for both. The fingers are the power, and the cloth to be cut, the resistance to be overcome.

Pincers, forceps, and sugar cutters, are examples of this kind of lever.

A common scale-beam, used for weighing, is a lever, suspended at the centre of gravity, so that the two arms balance each other. Hence the machine is called a *balance.* The fulcrum, or what is called the *pivot*, is sharpened, like a wedge, and made of hardened steel, so as much as possible to avoid friction.

Fig. 45.



A dish is suspended by cords to each end or arm of the lever, for the purpose of holding the articles to be weighed. When the whole is suspended at the point *a*, fig. 45, the beam or lever ought to remain in a horizontal position, one of its ends being exactly as high as the other. If the weights in the two dishes are equal, and the support exactly in the centre, they will always hang as represented in the figure.

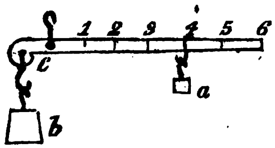
A very slight variation of the point of support towards one

What is the rule for finding the proportions between the weight and power? Give an illustration of this rule. What instruments operate on the principle of this lever? When the scissors are used, what is the resistance, and what the power? In the common scale-beam, where is the fulcrum? In what position ought the scale-beam to hang?

end of the lever, will make a difference in the weights employed to balance each other. In weighing a pound of sugar, with a scale beam of eight inches long, if the point of support is half an inch too near the weight, the buyer would be cheated nearly one ounce, and consequently nearly one pound in every sixteen pounds. This fraud might instantly be detected by changing the places of the sugar and weight, for then the difference would be quite material, since the sugar would then seem to want twice as much additional weight as it did really want.

The *steel-yard* differs from the balance, in having its support near one end, instead of in the middle, and also in having the weights suspended by hooks, instead of being placed in a dish.

Fig. 46.

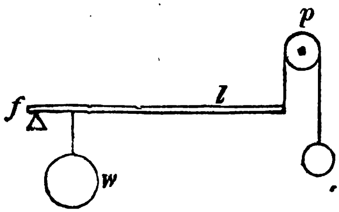


If we suppose the beam to be 7 inches long, and the hook, *c*, fig. 46, to be one inch from the end, then the pound weight *a*, will require an additional pound at *b*, for every inch it is moved from it. This, however, supposes that the bar will balance itself, before any weights are attached to it.

In the kind of lever described, the weight to be raised is on one side of the fulcrum, and the power on the other. Thus the fulcrum is between the power and the weight.

There is another kind of lever, in the use of which, the weight is placed between the fulcrum and the hand. In other words, the weight to be lifted, and the power by which it is moved, are on the same side of the prop.

Fig. 47.



This arrangement is represented by fig. 47, where *w* is the weight, *l* the lever, *f* the fulcrum, and *p* a pulley, over which a string is thrown, and a small weight suspended, as the power. In the common use of a lever of the first kind, the force is

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How may a fraudulent scale-beam be made? How may the cheat be detected? How does the steel-yard differ from the balance? In the first kind of lever, where is the fulcrum, in respect to the weight and power? In the second kind, where is the fulcrum, in respect to the weight and power?

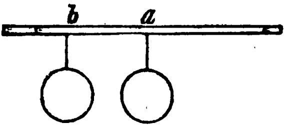
gained by bearing down the long arm of the lever, which is called *prying*. In the second kind, the force is gained by carrying the long arm in a contrary direction, or upward, and this is called *lifting*.

Levers of the second kind are not so common as the first, but are frequently used for certain purposes. The oars of a boat are examples of the second kind. The water against which the blade of the oar pushes, is the fulcrum, the boat is the weight to be moved, and the hands of the man the power.

Two men carrying a load between them on a pole, is also an example of this kind of lever. Each man acts as the power in moving the weight, and at the same time each becomes a fulcrum in respect to the other.

If the weight happens to slide on the pole, the man towards whom it goes, has to bear more of it in proportion as its distance from him is less than before.

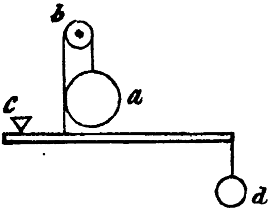
Fig. 48.



A load at *a*, fig. 48, is borne equally by the two men, being equally distant from each; but at *b*, three quarters of its weight would be on the man at that end, because three quarters of the length of the lever would be on the side of the other man.

In the third, and last kind of lever, the weight is placed at one end, the fulcrum at the other end, and the power between them, or the hand is between the fulcrum and the weight to be lifted.

Fig. 49



This is represented by fig. 49, where *c* is the fulcrum, *a* the power, suspended over the pulley *b*, and *d* is the weight to be raised.

This kind of lever works to great disadvantage, since the power must be greater than the weight. It is therefore seldom used, except in cases

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What is the action of the first kind called? What is the action of the second kind called? Give examples of the second kind of lever. In rowing a boat, what is the fulcrum, what the weight, and what the power? What other illustrations of this principle is given? In the third kind of lever, where are the respective places of the weight, power, and fulcrum?

where velocity and not force is required. In raising a ladder from the ground to the roof of a house, men are obliged, sometimes to make use of this principle, and the great difficulty of doing it, illustrates the mechanical disadvantage of this kind of lever.

We have now described the three kinds of levers, and we hope, have made the manner in which each kind acts, plain, by illustrations. But to make the difference between them still more obvious, and to avoid all confusion, we will here compare them together.

In the first kind, the weight or resistance, is on the short arm of the lever, the power, or hand, on the long arm, and the fulcrum between them. In the second kind, the weight is between the fulcrum, and the hand, or power; and, in the third kind, the hand is between the fulcrum and the weight.

Fig. 50.

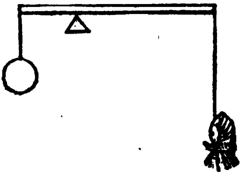


Fig. 51.

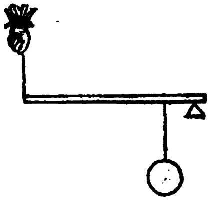
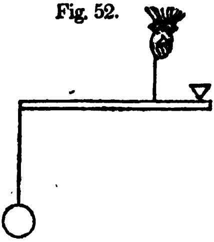


Fig. 52.



In fig. 50, the weight and hand both act downwards. In 51, the weight and hand act in contrary directions, the hand upwards, and the weight downwards, the weight being between them. In 52, the hand and weight also act in contrary directions, but the hand is between the fulcrum and the weight.

What is the disadvantage of this kind of lever? Give an example of the use of the third kind of lever. In what direction do the hand and weight act, in the first kind of lever? In what direction do they act in the second kind? In what direction do they act in the third kind?

Compound Lever.—When several simple levers are connected together, and act one upon the other, the machine is called a *compound lever*. In this machine, as each lever acts as an individual, and with a force equal to the action of the next lever upon it, the force is increased or diminished, and becomes greater or less, in proportion to the number or kind of levers employed.

We will illustrate this kind of lever by a single example, but must refer the inquisitive student to more extended works for a full investigation of the subject.

Fig. 53.

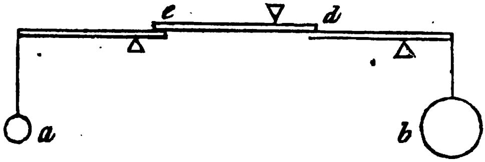


Fig. 53, represents a compound lever, consisting of 3 simple levers of the first kind.

In calculating the force of this lever, the rule applies, which has already been given for the simple lever, namely, the length of the long arm is to be multiplied by the moving power, and that of the short one, by the weight, or resistance. Let us suppose, then, that the three levers in the figure are of the same length, the long arms being six inches, and the short ones, two inches long, required, the weight which a moving power of 1 pound at *a* will balance at *b*. In the first place, 1 pound at *a*, would balance 3 pounds at *e*, for the *lever* being 6 inches, and the power 1 pound, 6×1=6, and the short one being 2 inches, 2×3=6. The long arm of the second lever being also 6 inches, and moved with a power of 3 pounds, multiply the 3 by 6=18; and multiply the length of the short arm, being 2 inches, by 9=18. These two products being equal, the power upon the long arm of the third lever, at *d*, would be 9 pounds. 9 pounds×6=54, and 27×2, is 54; so that 1 pound at *a* would balance 27 at *b*.

The increase of force is thus slow, because the proportion between the long and short arms, is only as 2 to 6, or in the proportions of 1, 3, 9.

What is a compound lever? By what rule is the force of the compound lever calculated? How many pounds weight will be raised by three levers connected, of eight inches each, with the fulcrum two inches from the end, by a power of one pound?

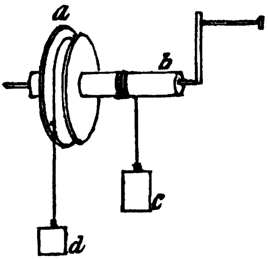
Now suppose the long arms of these levers to be 18 inches, and the short ones 1 inch, and the result will be surprisingly different, for then 1 pound at *a* would balance 18 pounds at *e*, and the second lever would have a power of 18 pounds. This being multiplied by the length of the lever, 18×18=324 pounds at *d*. The third lever would thus be moved by a power of 324 pounds, which, multiplied by 18 inches for the weight it would raise, would give 5832 pounds.

The compound lever is employed in the construction of *weighing machines*, and particularly, in cases where great weights are to be determined, in situations where other machines would be inconvenient, on account of their occupying too much space.

Wheel and Axle.

The mechanical power, next to the lever in simplicity, is the *wheel and axle.* It is, however, much more complex than the lever. It consists of two wheels, one of which is larger than the other, but the small one passes through the larger, and hence both have a common centre, on which they turn.

Fig. 54.

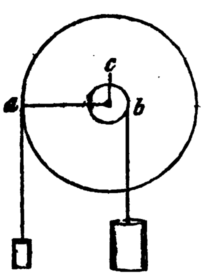


The manner in which this machine acts, will be understood by fig. 54. The large wheel *a*, on turning the machine, will take up, or throw off as much more rope than the small wheel or axle *b*, as its circumference is greater. If we suppose the circumference of the large wheel to be four times that of the small one, then it will take up the rope four times as fast. And because *a* is four times as large as *b*, 1 pound at *d* will balance 4 pounds at *c*, on the opposite side.

The principle of this machine is that of the lever, as will be apparent by an examination of fig. 55.

If the long arms of the levers be 18 inches, and the short one, one inch, how much will a power of one pound balance? In what machines is the compound lever employed? What advantages do these machines possess over others? What is the next simple mechanical power to the lever? Describe this machine. Explain fig. 54. On what principle does this machine act?

Fig. 55.

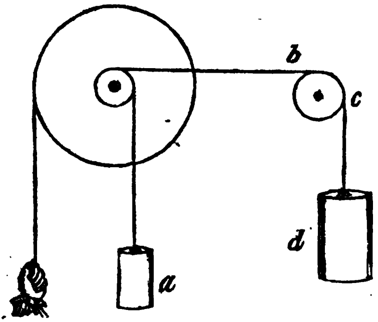


This figure represents the machine endwise, so as to show in what manner the lever operates. The two weights hanging in opposition to each other, the one on the wheel at *a*, and the other on the axle at *b*, act in the same manner as if they were connected by the horizontal lever *a b*, passing from one to the other, having the common centre, *c*, as a fulcrum between them.

The wheel and axle, therefore, acts like a constant succession of levers, the long arm being half the diameter of the wheel, and the short one half the diameter of the axle; the common centre of both being the fulcrum. The wheel and axle has, therefore, been called the *perpetual* lever.

The great advantage of this mechanical arrangement is, that while a lever of the same power can raise a weight but a few inches at a time, and then only in a certain direction, this machine exerts a continual force, and in any direction wanted. To change the direction, it is only necessary that the rope by which the weight is to be raised, should be carried in a line perpendicular to the axis of the machine, to the place below which the weight lies, and there be let fall over a pulley.

Fig. 56.



Suppose the wheel and axle, fig. 56, is erected in the third story of a store house, with the axle over the scuttles, or doors through the floors, so that goods can be raised by it from the ground floor, in the direction of the weight *a*. Suppose also, that the same store stands on a wharf, where ships come up to

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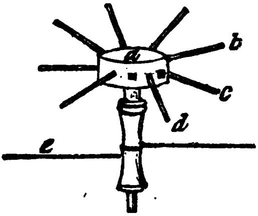
In fig. 55, which is the fulcrum, and which the two arms of the lever? What is this machine called, in reference to the principle on which it acts? What is the great advantage of this machine over the lever and other mechanical powers? Describe fig. 56, and point out the manner in which weights can be raised by letting fall a rope over the pulley.

its side, and goods are to be removed from the vessels into the upper stories. Instead of removing the goods into the store, and hoisting them in the direction of *a*, it is only necessary to carry the rope *b*, over the pulley *c*, which is at the end of a strong beam projecting out from the side of the store, and then the goods will be raised in the direction of *d*, thus saving the labor of moving them twice.

The wheel and axle, under different forms, is applied to a variety of common purposes.

Fig. 57.

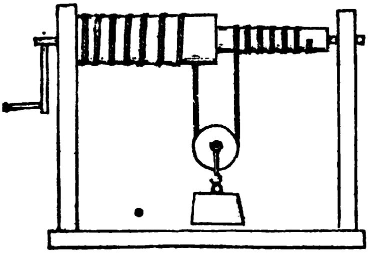


The *capstan*, in universal use, on board of ships and other vessels, is an axle placed upright, with a head, or drum, *a*, fig. 57, pierced with holes, for the levers *b*, *c*, *d*. The weight is drawn by the rope *e*, passing two or three times round the axle to prevent its slipping.

This is a very powerful and convenient machine. When not in use, the levers are taken out of their places and laid aside, and when great force is required, two or three men can push at each lever.

The common windlass for drawing water, is another modification of the wheel and axle. The *winch*, or *crank*, by which it is turned, is moved around by the hand, and there is no difference in the principle, whether a whole wheel is turned, or a single spoke. The winch, therefore, answers to the wheel, while the rope is taken up, and the weight raised by the axle, as already described.

Fig. 58.



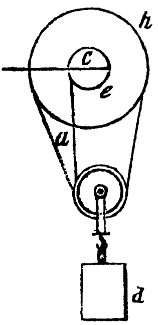
In cases where great weights are to be raised, and it is required that the machine should be as small as possible, on account of room, the simple wheel and axle, modified as represented by fig. 58, is sometimes used.

The axle may be considered in two parts, one

What is the capstan? Where is it chiefly used? What are the peculiar advantages of this form of the wheel and axle? In the common windlass, what part answers to the wheel?

of which is larger than the other. The rope is attached by its two ends, to the ends of the axle, as seen in the figure. The weight to be raised is attached to a small pulley, or wheel, round which the rope passes. The elevation of the weight may be thus described. Upon turning the axle, the rope is coiled around the larger part, and at the same time it is thrown off the smaller part. At every revolution, therefore, a portion of the rope will be drawn up, equal to the circumference of the thicker part, and at the same time a portion, equal to that of the thinner part, will be let down. On the whole, then, one revolution of the machine will shorten the rope where the weight is suspended, just as much as the difference between the circumference of the two parts.

Fig. 59.



Now to understand the principle on which this machine acts, we must refer to fig. 59, where it is obvious that the two parts of the rope *a* and *b*, equally support the weight *d*, and that the rope, as the machine turns, passes from the small part of the axle *e*, to the large part *h*, consequently the weight does not rise in a perpendicular line towards *c*, the centre of both, but in a line between the outsides of the large and small parts. Let us consider what would be the consequence of changing the rope *a* to the larger part of the axle, so as to place the weight in a line perpendicular to the axis of motion. In this case, it is obvious that the machine would be in equilibrium, since the weight *d*, would be divided between the two sides equally, and the two arms of a lever passing through the centre *c*, would be of equal length, and therefore no advantage would be gained. But in the actual arrangement, the weight being sustained equally by the large and small parts, there is involved a lever power, the long arm of which is equal to half the diameter of the large part, while the short arm is equal to half the diameter of the small part, the fulcrum being between them.

Explain fig. 58. Why is the rope shortened, and the weight raised? What is the design of fig. 59? Does the weight rise perpendicular to the axis of motion? Suppose the cylinder was, throughout, of the same size, what would be the consequence? On what principle does this machine act? Which are the long and short arms of the lever, and where is the fulcrum?

As the wheel and axle is only a modification of the simple lever, so a system of wheels acting on each other, and transmitting the power to the resistance, is only another form of the compound lever.

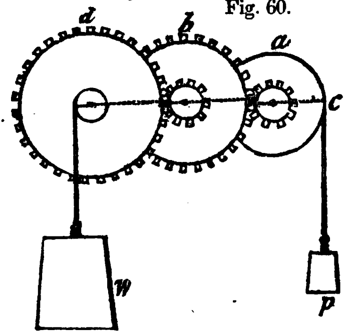


Fig. 60.

Such a combination is shown at fig. 60. The first wheel, *a*, by means of the teeth, or cogs around its axle, moves the second wheel, *b*, with a force equal to that of a lever, the long arm of which extends from the centre of the wheel and axle to the circumference of the wheel, where the power *p*, is suspended, and the short arm from the same centre to the ends of the cogs. The dotted line *c*, passing through the centre of the wheel *a*, shows the position of the lever, as the wheel now stands. The centre on which both wheels turn, it will be obvious, is the fulcrum of this lever. As the wheel turns, the short arm of this lever will act upon the long arm of the next lever by means of the teeth on the circumference of the wheel *b*, and this again through the teeth on the axle of *b*, will transmit its force to the circumference of the wheel *d*, and so by the short arm of the third lever to the weight *w*. As the power or small weight falls, therefore, the resistance, *w*, is raised, with the multiplied force of three levers, acting on each other.

In respect to the force to be gained by such a machine, suppose the number of teeth on the axle of the wheel *a*, to be six times less than the number of those on the circumference of the wheel *b*, then *b* would only turn round once, while *a* turned six times. And in like manner, if the number of teeth on the circumference of *d*, be six times greater than those on the axle of *b*, then *d* would turn once, while *b* turned six times. Thus six revolutions of *a* would make *b* revolve once, and six revolutions of *b*, would make *d* revolve once. Therefore *a* makes thirty-six revolutions, while *d* makes only one.

On what principle does a system of wheels act, as represented in fig. 60? Explain fig. 60, and show how the power *p* is transferred by the action of levers to *w*.

The diameter of the wheel *a*, being three times the diameter of the axle of the wheel *d*, and its velocity of motion being 36 to 1, 3 times 36 will give the weight which a power of 1 pound at *p*, would raise at *w*. Thus 36×3=108. One pound at *p* would therefore balance 108 pounds at *w*.

If the student has attended closely to what has been said on mechanics, he will now be prepared to understand, that no machine, however simple or complex it may be, can *create* the least degree of force. It is true, that one man with a machine, may apply a force which a hundred could not exert with their hands, but then it would take him a hundred times as long.

Suppose there are twenty blocks of stone to be moved a hundred feet; perhaps twenty men, by taking each a block, would move them all in a minute. One man, with a capstan, we will suppose, may move them all at once, but this man, with his lever, would have to make one revolution for every foot he drew the whole load towards him, and therefore to make one hundred revolutions to perform the whole work. It would also take him twenty times as long to do it, as it took the twenty men. His task, indeed, would be more than twenty times harder than that performed by the twenty men, for in addition to moving the stone, he would have the friction of the machinery to overcome, which commonly amounts to nearly one third of the force employed.

Hence there would be an actual loss of power by the use of the capstan, though it might be a convenience for the one man to do his work by its means, rather than to call in nineteen of his neighbours to assist him.

The same principle holds good in respect to other machinery, where the strength of man is employed as the power, or prime mover. There is no advantage gained, except that of convenience. In the use of the most simple of all machines, the lever, and where, at the same time, there is the least force lost by friction, there is no actual gain of power, for what seems to be gained in force is always lost in velocity. Thus, if a lever is of such length to raise 100 pounds an inch by the power of one pound, its long arm must pass through a

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What weight will one pound at *p* balance at *w*? Is there any actual power gained by the use of machinery? Suppose 20 men to move 20 stones to a certain distance with their hands, and one man moves them back to the same place with a capstan, which performs the most actual labor? Why? Why, then, is machinery a convenience?

space of 100 inches. Thus, what is gained in one way is lost in another.

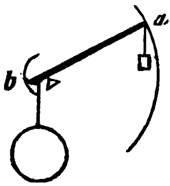
Any power by which a machine is moved, must be equal to the resistance to be overcome, and, in all cases where the power descends, there will be a proportion between the velocity with which it moves downwards, and the velocity with which the weight moves upwards. There will be no difference in this respect, whether the machine be simple or compound, for if its force be increased by increasing the number of levers, or wheels, the velocity of the moving power must also be increased, as that of the resistance is diminished.

There being, then, always a proportion, between the velocity with which the moving force descends, and that with which the weight ascends, whatever this proportion may be, it is necessary that the power should have to the resistance the same ratio that the velocity of the resistance has to the velocity of the power. In other words, "*The power multiplied by the space through which it moves, in a vertical direction, must be equal to the weight multiplied by the space through which it moves in a vertical direction.*"

This law is known under the name of "the law of virtual velocities," and is considered the *golden rule* of mechanics.

This principle has already been explained, while treating of the lever; but that the student should want nothing to assist him in clearly comprehending so important a law, we will again illustrate it in a different manner.

Fig. 61.



Suppose the weight of ten pounds to be suspended on the short arm of the lever, fig. 61, and that the fulcrum is only one inch from the weight; then, if the lever be ten inches long, on the other side of the fulcrum, one pound at *a* would raise, or balance, the ten pounds at *b*. But in raising the ten pounds one inch in a vertical direction, the long arm of the lever must fall

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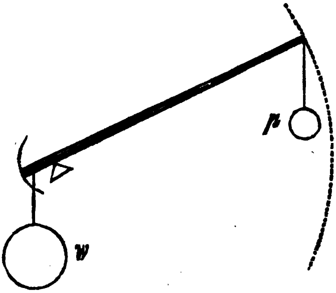
In the use of the lever, what proportion is there between the force of the short arm, and the velocity of the long arm? How is this illustrated? It is said, that the velocity of the power downwards, must be in proportion to that of the weight upwards? Does it make any difference, in this respect, whether the machine be simple or compound? What is the golden rule of mechanics? Under what name is this law known? Explain fig. 61, and show how the rule is illustrated by that figure.

ten inches in a vertical direction, and therefore the velocity of *a* would be ten times the velocity of *b*.

The application of this law, or rule, is apparent. The power is one pound, and the space through which it falls is 10 inches, therefore 10×1=10. The weight is 10 pounds, and the space through which it rises is one inch, therefore 1×10=10.

Thus the power, multiplied by the space through which it moves, is exactly equal to the weight, multiplied by the space through which it moves.

Fig. 62.



Again, suppose the lever fig. 62, to be thirty inches long from the fulcrum to the point where the power *p* is suspended, and that the weight *w* is two inches from the fulcrum. If the power be 1 pound, the weight must be fifteen pounds, to produce equilibrium, and the power *p* must fall thirty inches, to raise the weight *w* two inches. Therefore the power being 1 pound, and the space 30 inches, 30×1=30. The weight being 15 pounds, and the space 2 inches, 15×2=30.

Thus the power, multiplied by the space through which it falls, and the weight, multiplied by the space through which it rises, are equal.

However complex the machine may be, by which the force of a descending power is transmitted to the weight to be raised, the same rule will apply, as it does to the action of the simple lever.

The Pulley.

A *pulley*, consists of a wheel, which is grooved on the edge, and which is made to turn on its axis, by a chord passing over it.

Explain fig. 62, and show how the same rule is illustrated by it. What is said of the application of this rule to complex machines? What is a pulley?

Fig. 63.

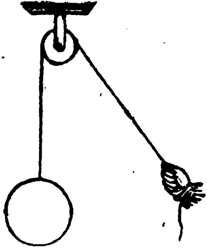


Fig. 63 represents a *simple pulley*, with a single fixed wheel. In other forms of the machine, the wheel moves up and down, with the weight.

The pulley is arranged among the simple mechanical powers; but when several are connected, the machine is called a *system of pulleys*, or a *compound pulley*.

One of the most obvious advantages of the pulley is, its enabling men to exert their own power, in places where they cannot go themselves. Thus, by means of a rope and wheel, a man can stand on the deck of a ship, and hoist a weight to the topmast.

By means of two fixed pulleys, a weight may be raised upward, while the power moves in a horizontal direction. The weight will also rise vertically through the same space that the rope is drawn horizontally.

Fig. 64.

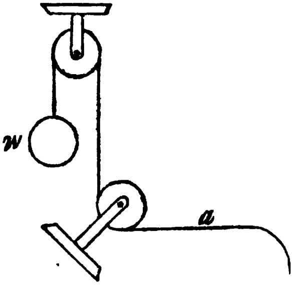


Fig. 64 represents two fixed pulleys, as they are arranged for such a purpose. In the erection of a lofty edifice, suppose the upper pulley to be suspended to some part of the building; then a horse, pulling at the rope *a*, would raise the weight *w* vertically, as far as he went horizontally.

In the use of the *wheel* of the pulley, there is no mechanical advantage, except that which arises from removing the friction, and diminishing the imperfect flexibility of the rope.

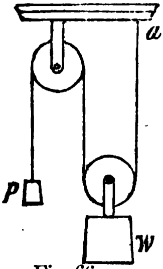
In the mechanical effects of this machine, the result would be the same, did it slide on a smooth surface with the same ease that its motion makes the wheel revolve.

The action of the pulley is on a different principle from that of the wheel and axle. A system of wheels, as already explained, acts on the same principle as the compound lever.

What is a simple pulley? What is a system of pulleys, or a compound pulley? What is the most obvious advantage of the pulley? How must two fixed pulleys be placed, to raise a weight vertically, as far as the power goes horizontally? What is the advantage of the wheel of the pulley?

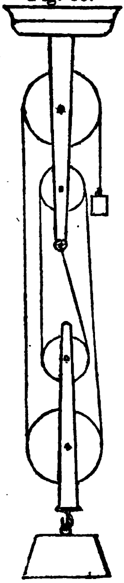
But the mechanical efficacy of a system of pulleys, is derived entirely from the division of the weight among the strings employed in suspending it. In the use of the single *fixed* pulley, there can be no mechanical advantage, since the weight rises as fast as the power descends. This is obvious by fig. 63; where it is also apparent that the power and weight must be exactly equal, to balance each other.

Fig. 65.



In the single *moveable* pulley, fig. 65, the same rope passes from the fixed point *a*, to the power *p*. It is evident, here, that the weight is supported equally by the two parts of the string between which it hangs. Therefore, if we call the weight *w* ten pounds, five pounds will be supported by one string, and five by the other. The power, then, will support twice its own weight, so that a person pulling with a force of five pounds at *p*, will raise ten pounds at *w*. The mechanical force, therefore, in respect to the power, is as two to one.

Fig. 66.



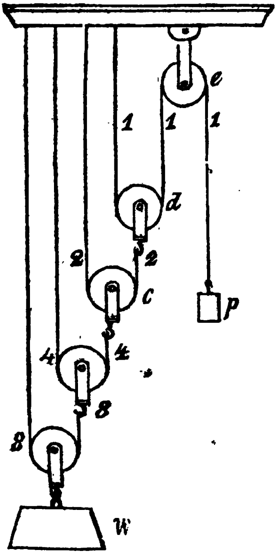
In this example, it is supposed there are only two ropes, each of which bears an equal part of the weight.

If the number of ropes be increased, the weight may be increased with the same power; or the power may be diminished in proportion as the number of ropes is increased. In fig. 66, the number of ropes sustaining the weight is four, and therefore, the weight may be four times as great as the power. This principle must be evident, since it is plain that each rope sustains an equal part of the weight. The weight may therefore be considered as divided into four parts, and each part sustained by one rope.

In fig. 67, there is a system of pulleys represented, in which the weight is sixteen times the power.

How does the action of the pulley differ from that of the wheel and axle? Is there any mechanical advantage in the fixed pulley? What weight at *p*, fig. 65, will balance ten pounds at *w*? Suppose the number of ropes to be increased, and the weight increased, must the power be increased also?

Fig. 67.



The tension of the rope *d*, *e*, is evidently equal to the power, *p*, because it sustains it: *d*, being a moveable pulley, must sustain a weight equal to twice the power; but the weight which it sustains, is the tension of the second rope, *d*, *c*. Hence the tension of the second rope is twice that of the first, and, in like manner, the tension of the third rope is twice that of the second, and so on, the weight being equal to twice the tension of the last rope.

Suppose the weight *w*, to be sixteen pounds, then the two ropes, 8 and 8, would sustain just 8 pounds each, this being the whole weight divided equally between them. The next two ropes, 4 and 4, would evidently sustain but half this whole weight, because the other half is already sustained by a rope, fixed at its upper end. The next two ropes sustain but half of 4, for the same reason; and the next pair, 1 and 1, for the same reason, will sustain only half of 2. Lastly, the power *p*, will balance two pounds, because it sustains but half this weight, the other half being sustained by the same rope, fixed at its upper end.

It is evident, that in this system, each rope and pulley which is added, will double the effect of the whole. Thus, by adding another rope and pulley beyond 8, the weight *w* might be 32 pounds, instead of 16, and still be balanced by the same power.

In our calculations of the effects of pullies, we have allowed nothing for the weight of the pullies themselves, or for the friction of the ropes. In practice, however, it will be found,

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Suppose the weight, fig. 66, to be 32 pounds, what will each rope bear? Explain fig. 67, and show what part of the weight each rope sustains, and why 1 pound at *p*, will balance 16 pounds at *w*. Explain the reason why each additional rope and pulley will double the effect of the whole, or why its weight may be double by that of all the others, with the same power.

that nearly one third must be allowed for friction, and that the power, therefore, to actually raise the weight, must be about one third greater than has been allowed.

The pulley, like other machines, obeys the law of virtual velocities, already applied to the lever and wheel. *Thus,* "*in a system of pullies, the ascent of the weight, or resistance, is as much less than the descent of the power, as the weight is greater than the power.*" If, as in the last example, the weight is 16 pounds, and the power 1 pound, the weight will rise only one foot, while the power descends 16 feet.

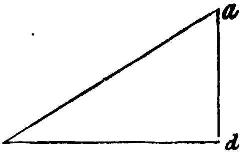
In the single fixed pulley, the weight and power are equal, and consequently, the weight rises as fast as the power descends.

With such a pulley, a man may raise himself up to the mast head by his own weight. Suppose a rope is thrown over a pulley, and a man ties one end of it round his body, and takes the other end in his hands. He may raise himself up, because, by pulling with his hands, he has the power of throwing more of his weight on that side than on the other, and when he does this, his body will rise. Thus, although the power and the weight are the same individual, still the man can change his centre of gravity, so as to make the power greater than the weight, or the weight greater than the power, and thus can elevate one half his weight in succession.

The Inclined Plane.

The fourth simple mechanical power is the *inclined plane.*

Fig. 68.



This power consists of a plain, smooth surface, which is inclined towards, or from the earth. It is represented by fig. 68, where from *a* to *b* is the *inclined plane;* the line from *d* to *a*, is its *height*, and that from *b* to *d*, its *base.*

A board, with one end on the ground, and the other end resting on a block, becomes an inclined plane.

This machine, being both useful and easily constructed, is in very general use, especially where heavy bodies are to be raised only to a small height. Thus a man, by means of an

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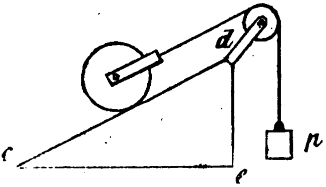
In compound machines, how much of the power must be allowed for the friction? How may a man raise himself up by means of a rope and single fixed pulley? What is an inclined plane?

inclined plane, which he can readily construct with a board, or couple of bars, can raise a load into his wagon, which ten men could not lift with their hands.

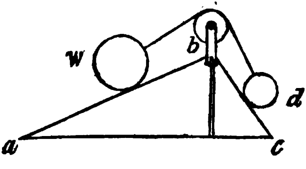
The power required to force a given weight up an inclined plane, is in a certain proportion to its height, and the length of its base, or, in other words, the force must be in proportion to the rapidity of its inclination.

Fig. 69.



The power *p*, fig. 69, pulling a weight up the inclined plane, from *c* to *d*, only raises it in a perpendicular direction from *e* to *d*, by acting along the whole length of the plane. If the plane be twice as long as it is high, that is, if the line from *c* to *d* be double the length of that from *e* to *d*, then one pound at *p* will balance two pounds any where between *d* and *c*. It is evident, by a glance at this fig., that were the base, that is, the line from *e* to *c*, lengthened, the height from *e* to *d* being the same, that a less power at *p*, would balance an equal weight any where on the inclined plane; and so, on the contrary, were the base made shorter, that is, the plane more steep, the power must be increased in proportion.

Fig. 70.

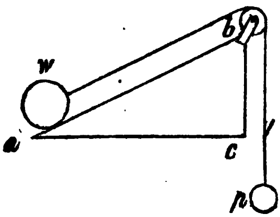


Suppose two inclined planes, fig. 70, of the same height, with bases of different lengths; then the weight and power will be to each other as the length of the planes. If the length from *a* to *b*, is two feet, and that from *b* to *c*, one foot, then two pounds at *d* will balance four pounds at *w*, and so in this proportion, whether the planes be longer or shorter.

The same principle, with respect to the vertical velocities of the weight and power, applies to the inclined plane, in common with the other mechanical powers.

On what occasions is this power chiefly used? Suppose a man wants to load a barrel of cider into his wagon, how does he make an inclined plane for this purpose? To roll a given weight up an inclined plane, to what must the force be proportioned? Explain fig. 69. If the length of the long plane, fig. 70, be double that of the short one, what must be the proportion between the power and the weight?

Fig. 71.



Suppose the inclined plane, fig. 71, to be two feet from *a* to *b*, and one foot from *c* to *b*, then, as we have already seen by fig. 69, a power of one pound at *p*, would balance a weight of two pounds at *w*. Now, in the fall of the power to draw up the weight, it is obvious that its vertical descent must be just twice the vertical ascent of the weight; for the power must fall down the distance from *a* to *b*, to draw the weight that distance; but the vertical height to which the weight *w* is raised, is only from *c* to *b*. Thus the power, being two pounds, must fall two feet, to raise the weight, four pounds, one foot; and thus the power and weight, multiplied by the several velocities, are equal.

The Wedge.

The next simple mechanical power is the *wedge*. This instrument may be considered as two inclined planes, placed base to base. It is much employed for the purpose of splitting or dividing solid bodies, such as wood and stone.

Fig. 72.

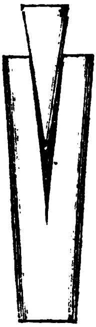


Fig. 72 represents such a wedge as is usually employed in cleaving timber. This instrument is also used in raising ships and preparing them to launch, and for a variety of other purposes. Nails, awls, needles, and many cutting instruments, act on the principle of this machine.

There is much difficulty in estimating the power of the wedge, since this depends on the force, or the number of blows given it, together with the obliquity of its sides. A wedge of great obliquity would require hard blows to drive it forward, for the same reason that a plane much inclined, requires much force to roll a heavy body up it. But were the obliquity of the wedge, and

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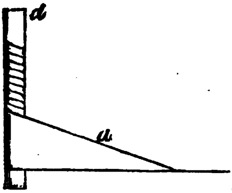
What is said of the application of the law of vertical velocities to the inclined plane? Explain fig. 70, and show why the power must fall twice as far as the weight rises. On what principle does the wedge act? In what cases is this power useful? What common instruments act on the principle of the wedge? What difficulty is there in estimating the power of the wedge?

the force of each blow given, still it would be difficult to ascertain the exact power of the wedge in ordinary cases, for, in the splitting of timber, and stone, for instance, the divided parts act as levers, and thus greatly increase the power of the wedge. Thus, in a log of wood, six feet long, when split one half of its length, the other half is divided with ease, because the two parts act as levers, the lengths of which constantly increase, as the cleft extends from the wedge.

The Screw.

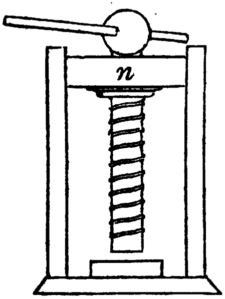
The *screw* is the fifth and last simple mechanical power. It may be considered as a modification of the inclined plane, or as a winding wedge. It is an inclined plane running spirally round a spindle, as will be seen by fig. 73. Suppose *a* to be a piece of paper cut into the form of an inclined plane, and rolled round the piece of wood *d;* its edge would form the spiral line, called the *thread* of the screw.

Fig. 73.



If the finger be placed between the two threads of a screw, and the screw be turned round once, the finger will be raised upward equal to the distance of the two threads apart. In this manner the finger is raised up the inclined plane, as it runs round the cylinder.

Fig. 74.



The power of the screw is transmitted and employed by means of another screw called the *nut*, through which it passes. This has a spiral groove running through it, which exactly fits the thread of the screw.

If the nut is fixed, the screw itself, on turning it round, advances forward; but if the screw is fixed, the nut, when turned, advances along the screw.

Fig. 74, represents the first kind of screw, being such as is commonly used in pressing paper, and other substances. The nut, *n*, through which

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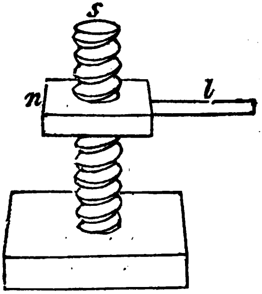
On what principle does the screw act? How is it shown that the screw is a modification of the inclined plane? Explain fig. 74. Which is the screw, and which the nut?

the screw passes, answers also for one of the beams of the press. If the screw be turned to the right, it will advance downwards, while the nut stands still.

Fig. 75.



A screw of the second kind is represented by fig. 75. In this, the screw is fixed, while the nut, *n*, by being turned by the lever, *l*, from left to right, will advance down the screw.

In practice, the screw is never used as a simple mechanical machine; the power being always applied by means of a lever, passing through the head of the screw, as in fig. 74, or into the nut, as in fig. 75.

The screw, therefore, acts with the combined power of the inclined plane and the lever, and its force is such as to be limited only by the strength of the materials of which it is made.

In investigating the effects of this machine, we must, therefore, take into account both these simple mechanical powers, so that the screw now becomes really a compound engine.

In the inclined plane, we have already seen, that the less it is inclined, the more easy is the ascent up it. In applying the same principle to the screw, it is obvious, that the greater the distance of the threads from each other, the more rapid the inclination, and consequently, the greater must be the power to turn it, under a given weight. On the contrary, if the thread inclines downwards but slightly, it will turn with less power, for the same reason that a man can roll a heavy weight up a plane but little inclined. Therefore, the finer the screw, or the nearer the threads to each other, the greater will be the pressure under a given power.

Let us suppose two screws, the one having the threads one inch apart, and the other half an inch apart; then the force which the first screw will give with the same power at the

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Which way must the screw be turned, to make it advance through the nut? How does the screw, fig. 75, differ from fig. 74? Is the screw ever used as a simple machine? By what other simple power is it moved? What two simple mechanical powers are concerned in the force of the screw? Why does the nearness of the threads make a difference in the force of the screw?

lever will be only half that given by the second. The second screw must be turned twice as many times round as the first, to go through the same space, but what is lost in velocity is gained in power. At the lever of the first, two men would raise a given weight to a given height by making one revolution; while at the lever of the second, one man would raise the same weight to the same height, by making two revolutions.

It is apparent that the length of the inclined plane, up which a body moves in one revolution, is the circumference of the screw, and its height, the interval between the threads. The proportion of its power would therefore be "as the circumference of the screw, to the distance between the threads, so is the weight to the power."

By this rule the power of the screw alone can be found; but as this machine is moved by means of the lever, we must estimate its force by the combined power of both. In this case, the circumference described by the end of the lever employed, is taken, instead of the circumference of the screw itself. The means by which the force of the screw may be found, is therefore by multiplying the circumference which the lever describes by the power. Thus, "*the power multiplied by the circumference which it describes, is equal to the weight or resistance, multiplied by the distance between the two contiguous threads.*" Hence the efficacy of the screw may be increased, by increasing the length of the lever by which it is turned, or by diminishing the distance between the threads. If, then, we know the length of the lever, the distance between the threads, and the weight to be raised, we can readily calculate the power; or, the power being given, and the distance of the threads and the length of the lever known, we can estimate the weight the screw will raise.

Thus, suppose the length of the lever to be forty inches, the distance of the threads one inch, and the weight 8000 pounds; required the power, at the end of the lever, to raise the weight.

The lever being 40 inches, the diameter of the circle, which

Suppose one screw, with its threads one inch apart, and another half an inch apart, what will be their difference in force? What is the length of the inclined plane up which a body moves by one revolution of the screw? What would be the height to which the same body would move at one revolution? How is the force of the screw estimated? How may the efficacy of the screw be increased? The length of the lever, the distance between the threads, and the weight, being known, how can the power be found? Give an example.

the end describes, is 80 inches. The circumference is a little more than three times the diameter, but we will call it just three times. Then 80×3=240 inches, the circumference of the circle. The distance of the threads is 1 inch, and the weight 8,000 pounds. To find the power, multiply the weight by the distance of the threads, and divide by the circumference of the circle. Thus

$$\overset{\text{circum.}}{240} \quad + \quad \overset{\text{in.}}{1} \quad :: \quad \overset{\text{weight.}}{8000} \quad = \quad \overset{\text{power.}}{33\tfrac{1}{3}}$$

The power at the end of the lever must therefore be 33⅓ pounds. In practice this power would require to be increased about one third, on account of friction.

The force of the screw is sometimes employed to turn a wheel, by acting on its teeth. In this case it is called the *perpetual screw.*

Fig. 76.

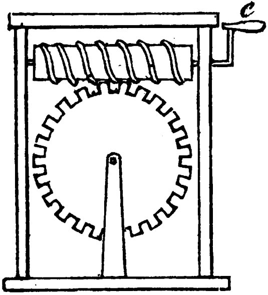

Fig. 76 represents such a machine. It is apparent, that by turning the crank *c*, the wheel will revolve, for the thread of the screw passes between the cogs of the wheel. By means of an axle, through the centre of this wheel, like the common wheel and axle, this becomes an exceedingly powerful machine, but like all other contrivances for obtaining great power, its effective motion is exceedingly slow. It has however some disadvantages, and particularly the great friction between the thread of the screw and the teeth of the wheel, which prevents it from being generally employed to raise weights.

We have now enumerated and described all the mechanical powers usually denominated simple. They are five in number, namely, the Lever, Wheel and Axle, Pulley, Wedge, Inclined Plane, and Screw.

In respect to the principle on which they act, they may be resolved into three simple powers, namely, the lever, the inclined plane, and the pulley; for it has been shown that the wheel and axle is only another form of the lever, and that the screw is but a modification of the inclined plane.

What is the screw called when it is employed to turn a wheel? What is the object of this machine for raising weights? How many simple mechanical powers are there? and what are they called? How can they be resolved into three simple powers?

It is surprising indeed, that these simple powers can be so arranged and modified, as to produce the different actions in all that vast variety of intricate machinery which men have invented and constructed.

The variety of motions we witness in the little engine which makes cards, by being supplied with wire for the teeth, and strips of leather to stick them through, would itself seem to involve more mechanical powers than those enumerated. This engine takes the wire from a reel, bends it into the form of teeth; cuts it off; makes two holes in the leather for the tooth to pass through; sticks it through; then gives it another bend, on the opposite side of the leather; graduates the spaces between the rows of teeth, and between one tooth and another; and at the same time, carries the leather backwards and forwards, before the point where the teeth are introduced, with a motion so exactly corresponding with the motions of the parts which make and stick the teeth, as not to produce the difference of a hair's breadth in the distance between them. All this is done without the aid of human hands, any farther than to put the leather in its place, and turn a crank; or, in some instances, many of these machines are turned at once, by means of three or four dogs, walking on an inclined plane which revolves.

Such a machine displays the wonderful ingenuity and perseverance of man, and at first sight would seem to set at naught the idea that the lever and wheel were the chief simple powers concerned in its motions. But when these motions are examined singly and deliberately, we are soon convinced that the wheel, variously modified, is the principal mechanical power in the whole engine.

It has already been stated, that notwithstanding the vast deal of time and ingenuity which men have spent on the construction of machinery, and in attempting to multiply their powers, there has, as yet, been none produced, in which the power was not obtained at the expense of velocity, or velocity at the expense of power; and therefore no actual force is ever generated by machinery.

Suppose a man able to raise a weight by means of a compound pulley of ten ropes, which it would take ten men to

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What is said of the card-making machine? What are the chief mechanical powers concerned in its motions? Is there any actual force generated by machinery? Can great velocity and great force be produced by the same machinery? Why not?

raise by one rope, without pulleys. If the weight is to be raised a yard, the ten men by pulling their rope a yard will do the work. But the man with the pulleys must draw his rope ten yards to raise the weight one yard, and in addition to this, he has to overcome the friction of the ten pulleys, making about one third more actual labor than was employed by the ten men. But notwithstanding these inconveniences, the use of machinery is of vast importance to the world.

On board of a ship, a few men will raise an anchor with a capstan, which it would take ten or twenty times the same number to raise without it, and thus the expense of shipping men expressly for this purpose is saved.

One man with a lever, may move a stone which it would take twenty men to move without it, and though it should take him twenty times as long, he would still be the gainer, since it would be more convenient, and less expensive for him to do the work himself, than to employ twenty others to do it for him.

When men employ the natural elements as a power to overcome resistance by means of machinery, there is a vast saving of animal labor. Thus mills, and all kinds of engines, which are kept in motion by the power of water, or wind, or steam, save animal labor equal to the power it takes to keep them in motion.

HYDROSTATICS.

Hydrostatics is the science which treats of the weight, pressure, and equilibrium of water, or other fluids, when in a state of rest.

Hydraulics is that part of the science of fluids which treats of water in motion, and the means of raising and conducting it in pipes, or otherwise, for all sorts of purposes.

The subject of water at rest, will first claim investigation, since the laws which regulate its motion will be best understood by first comprehending those which regulate its pressure.

A *fluid* is a substance whose particles are easily moved among each other, as air and water.

Which performs the greatest labor, ten men who lift a weight with their hands, or one man who does the same with ten pulleys? Why? What is hydrostatics? How does hydraulics differ from hydrostatics? What is a fluid?

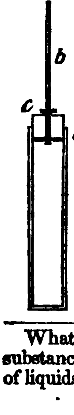
The air is called an *elastic* fluid, because it is easily compressed into a smaller bulk, and returns again to its original state when the pressure is removed. Water is called a *non-elastic* fluid, because it admits of little diminution of bulk under pressure.

The non-elastic fluids, are perhaps more properly called *liquids*, but both terms are employed to signify water and other bodies possessing its mechanical properties. The term fluid, when applied to the air, has the word elastic before it.

One of the most obvious properties of fluids, is the facility with which they yield to the impressions of other bodies, and the rapidity with which they recover their former state, when the pressure is removed. The cause of this, is apparently the freedom with which the particles of liquids slide over, or among each other; their cohesive attraction being so slight as to be overcome by the least impression. On this want of cohesion among their particles seem to depend the peculiar mechanical properties of these bodies.

In solids, there is such a connexion between the particles, that if one part moves, the other part must move also. But in fluids, one portion of the mass may be in motion, while the other is at rest. In solids, the pressure is always downwards, or towards the centre of the earth's gravity; but in fluids the particles seem to act on each other as wedges, and hence, when confined, the pressure is sideways, and even upwards, as well as downwards.

Fig. 77.



Water has commonly been called a non-elastic substance, but it is found that under great pressure its volume is diminished, and hence it is proved to be elastic. The most decisive experiments on this subject were made within a few years by Mr. Perkins.

The experiments were made by means of a hollow cylinder, fig. 77, which was closed at the bottom, and made water tight at the top, by a cap, screwed on. Through this cap at *a*, passed the rod *b*, which was five sixteenths of an inch in diameter. The rod was so nicely fitted to the cap, as also to be water tight. Around the rod at *c*, there was placed a flexible ring, which could be easily pushed up or down, but fitted so closely as to remain on any part where it was placed

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What is an elastic fluid? Why is air called an elastic fluid? What substances are called liquids? What is one of the most obvious properties of liquids? On what do the peculiar mechanical properties of fluids depend?

A cannon of sufficient size to receive this cylinder, which was three inches in diameter, was furnished with a strong cap and forcing pump, and set vertically into the ground. The cannon and cylinder were next filled with water, and the cylinder, with its rod drawn out, and the ring placed down to the cap, as in the figure, was plunged into the cannon. The water in the cannon was then subjected to an immense pressure by means of the forcing pump, after which, on examination of the apparatus, it was found that the ring *c*, instead of being where it was placed, was eight inches up the rod. The water in the cylinder being compressed into a smaller space, by the pressure of that in the cannon, the rod was driven in, while under pressure, but was forced out again by the expansion of the water, when the pressure was removed. Thus the ring on the rod would indicate the distance to which it had been forced in, during the greatest pressure.

This experiment proved that water under the pressure of one thousand atmospheres, that is, the weight of 15000 pounds to the square inch, was reduced in bulk about one part in 24.

So slight a degree of elasticity under such immense pressure, is not appreciable under ordinary circumstances, and therefore in practice, or in common experiments on this fluid, water is considered as non-elastic.

Equal pressure of Water.

The particles of water, and other fluids, when confined, press on the vessel which confines them, in all directions, both upwards, downwards, and sideways.

From this property of fluids, together with their weight, or gravity, very unexpected and surprising effects are produced

The effect of this property, which we shall first examine, is, that a quantity of water, however small, will balance another quantity however large. Such a proposition at first thought might seem very improbable. But on examination, we shall find that an experiment with a very simple apparatus will convince any one of its truth. Indeed, we every day see this principle established by actual experiment, as will be seen directly.

In what respect does the pressure of a fluid differ from that of a solid? Is water an elastic, or a non-elastic fluid? Describe fig. 77, and show how water was found to be elastic. In what proportion does the bulk of water diminish under a pressure of 15000 pounds to the square inch? In common experiments, is water considered elastic, or non-elastic? When water is confined, in what direction does it press?

Fig. 78.

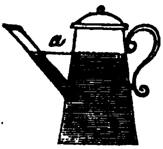
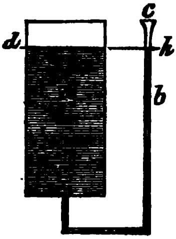


Fig. 78, represents a common coffee-pot, supposed to be filled up to the dotted line *a*, with a decoction of coffee, or any other liquid. The coffee, we know, stands exactly at the same height, both in the body of the pot, and in its spout. Therefore, the small quantity in the spout, balances the large quantity in the pot, or presses with the same force downwards, as that in the body of the pot presses upwards. This is obviously true, otherwise, the large quantity would sink below the dotted line, while that in the spout would rise above it, and run over.

Fig. 79.



The same principle is more strikingly illustrated by fig. 79.

Suppose the cistern *a* to be capable of holding one hundred gallons, and into its bottom there be fitted the tube *b*, bent, as seen in the figure, and capable of containing one gallon. The top of the cistern, and that of the tube being open, pour water into the tube at *c*, and it will rise up through the perpendicular bend into the cistern, and if the process be continued, the cistern will be filled by pouring water into the tube. Now, it is plain that the gallon of water in the tube, presses against the hundred gallons in the cistern with a force equal to the pressure of the hundred gallons, otherwise that in the tube would be forced upwards higher than that in the cistern, whereas, we find that the surfaces of both stand exactly at the same height.

From these experiments we learn, "*that the pressure of a fluid is not in proportion to its quantity, but to its height, and that a large quantity of water in an open vessel, presses downwards with no more force, than a small quantity of the same height.*"

In this respect, the size or shape of a vessel is of no consequence, for if a number of vessels, differing entirely from each other in figure, position, and capacity, have a communication made between them, and one be filled with water, the sur-

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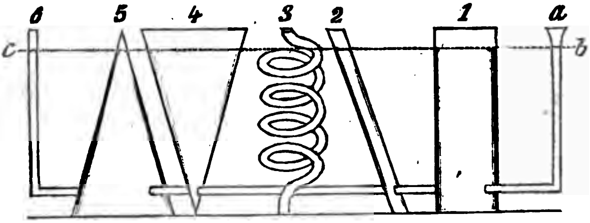
How does the experiment with the coffee-pot, show that a small quantity of liquid will balance a large one? Explain fig. 79, and show how the pressure in the tube is equal to the pressure in the cistern. What conclusion, or general truth, is to be drawn from these experiments? What difference does the shape or size of a vessel make in respect to the pressure of a fluid on its bottom?

face of the fluid, in all, will be at exactly the same elevation. If, therefore, the water stands at an equal height in all, the pressure in one must be just equal to that in another, and so equal to that in all the others.

Fig. 80.



To make this obvious, suppose a number of vessels, of different shapes and sizes, as represented by fig. 80, to have a communication between them, by means of a small tube, passing from the one to the other. If, now, one of these vessels be filled with water, or if water be poured into the tube *a*, all the other vessels will be filled, at the same instant, up to the line *b*, *c*. Therefore, the pressure of the water in *a*, balances that in 1, 2, 3, &c., while the pressure in each of these vessels, is equal to that in the other, and so an equilibrium is produced throughout the whole series.

If an ounce of water be poured into the tube *a*, it will produce a pressure on the contents of all the other vessels, equal to the pressure of all the others on the tube; for, it will force the water in all the other vessels to rise upwards to an equal height with that in the tube itself. Hence we must conclude, that the pressure in each vessel, is not only equal to that in any of the others, but also that the pressure in any one, is equal to that in all the others.

From this we learn, that the shape or size of a vessel has no influence on the pressure of its liquid contents, but that the pressure of water is as its height, whether the quantity be great or small. We learn also, that in no case will the weight of a quantity of liquid, however large, force another quantity, however small, above the level of its own surface.

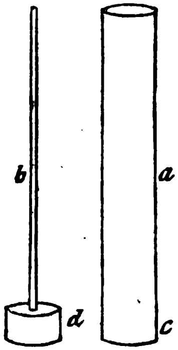
Explain fig. 80, and show how the equilibrium is produced. Suppose an ounce of water be poured into the tube *a*, what will be its effect on the contents of the other vessels? What conclusion is to be drawn from pouring the ounce of water into the tube *a*?

This is proved by experiment; for if, from a pond situated on a mountain, water be conveyed in an inch tube to the valley an hundred feet below, the water will rise just a hundred feet in the tube; that is, exactly to the level of the surface of the pond. Thus the water in the pond, and that in the tube, press equally against each other, and produce an exact equilibrium.

Thus far we have considered the fluid as acting only in vessels with open mouths, and therefore at liberty to seek its balance, or equilibrium by its own gravity. Its pressure, we have seen, is in proportion to its height, and not to its bulk.

Now, by other experiments it is ascertained *that the pressure of a liquid is in proportion to its height, and its area at the base.*

Fig. 81.



Suppose a vessel ten feet high, and two feet in diameter, such as is represented at *a*, fig. 81, to be filled with water; there would be a certain amount of pressure, say at *c*, near the bottom. Let *d* represent another vessel, of the same diameter at the bottom, but only a foot high, and closed at the top. Now if a small tube, say the fourth of an inch in diameter, be inserted into the cover of the vessel *d*, and this tube be carried to the height of the vessel *a*, and then the vessel and tube be filled with water, the pressure on the bottoms and sides of both vessels to the same height will be equal, and jets of water starting from *d*, and *c*, will have exactly the same force.

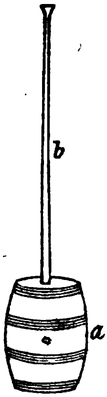
This might at first seem improbable, but to convince ourselves of its truth, we have only to consider that any impression made on one portion of the confined fluid in the vessel *d*, is instantly communicated to the whole mass. Therefore, the water in the tube *b* presses with the same force on every other portion of the water in *d*, as it does on that small portion over which it stands.

This principle is illustrated in a very striking manner by

What is the reason that a large quantity of water will not force a small quantity above its own level? Is the force of water in proportion to its height, or its quantity? How is a small quantity of water shown to press equal to a large quantity by fig. 81? Explain the reason why the pressure is as great at *d*, as at *c*.

the experiment, which has often been made, of bursting the strongest wine cask with a few ounces of water.

Fig. 82.



Suppose *a*, fig. 82, to be a strong cask already filled with water, and suppose the tube *b*, thirty feet high, to be screwed, water tight, into its head. When water is poured into the tube, so as to fill it gradually, the cask will show increasing signs of pressure, by emitting the water through the pores of the wood, and between the joints: and finally as the tube is filled, the cask will burst asunder.

The same apparatus will serve to illustrate the upward pressure of water; for if a small stop-cock be fitted to the upper head, on turning this, when the tube is filled, a jet of water will spirt up with a force, and to a height that will astonish all who never before saw such an experiment.

In theory, the water will spout to the same height with that which gives the pressure, but in practice, it is found to fall short, in the following proportions:

If the tube be twenty feet high, and the orifice for the jet half an inch in diameter, the water will spout nearly nineteen feet. If the tube be fifty feet high, the jet will rise upwards of forty feet, and if an hundred feet, it will rise above eighty feet. It is understood in every case, that the tubes are to be kept full of water.

The height of these jets show the astonishing effects that a small quantity of fluid produces when pressing from a perpendicular elevation.

An instrument called the hydrostatic bellows, also shows, in a striking manner, the great force of a small quantity of water, pressing in a perpendicular direction.

This instrument consists of two boards, connected together with strong leather, in the manner of the common bellows. It is then furnished with a tube *a*, fig. 83, which communicates between the two boards. A person standing on the upper board, may raise himself up by pouring water into the tube. If the tube holds an ounce of water, and has an area

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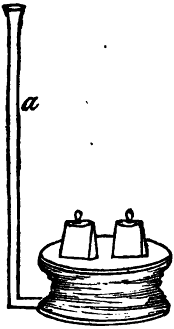
How is the same principle illustrated by fig. 82? How is the upward pressure of water illustrated by the same apparatus? Under the pressure of a column of water twenty feet high, what will be the height of the jet? Under a pressure of a hundred feet, how high will it rise?

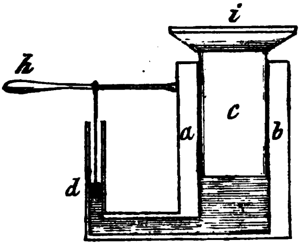
Fig. 83.



equal to a thousandth part of the area of the top of the bellows, one ounce of water in the tube will balance a thousand ounces placed on the bellows.

This property of water was applied by Mr. Bramah to the construction of his *hydraulic* press. But instead of a high tube of water, which in most cases could not be readily obtained, he substituted a strong forcing pump, and instead of the leather bellows, a metallic pump barrel, and piston.

Fig. 84.



This arrangement will be understood by fig. 84, where the pump barrel, *a*, *b*, is represented as divided lengthwise, in order to show the inside. The piston, *c*, is fitted so accurately to the barrel, as to work up and down water tight; both barre. and piston being made of iron. The thing to be broken, or pressed, is laid on the flat surface, *i*, there being above this, a strong frame to meet the pressure, not shown in the figure. The small forcing pump, of which *d* is the piston, and *h* the lever by which it is worked, is also made of iron.

Now, suppose the space between the small piston and the large one, at *w*, to be filled with water, then, on forcing down the small piston, *d*, there will be a pressure against the large piston, *c*, the whole force of which will be in proportion as the aperture in which *c* works, is greater than that in which *d* works. If the piston, *d*, is half an inch in diameter, and the piston, *c*, one foot in diameter, then the pressure on *c* will be 576 times greater than that on *d*. Therefore, if we suppose the pressure of the small piston to be one ton, the large piston will be forced up against any resistance, with a pressure equal

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What is the hydrostatic bellows? What property of water is this instrument designed to show? Explain fig. 84. Where is the piston? Which is the pump barrel, in which it works? In the hydrostatic press, what is the proportion between the pressure given by the small piston, and the force exerted on the large one?

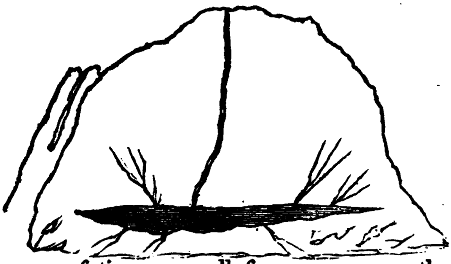
to the weight of 576 tons. It would be easy for a single man to give the pressure of a ton at *d*, by means of the lever, and therefore a man, with this engine, would be able to exert a force equal to the weight of near 600 tons.

It is evident, that the force to be obtained by this principle, can only be limited by the strength of the materials of which the engine is made. Thus, if a pressure of two tons be given to a piston, the diameter of which is only a quarter of an inch, the force transmitted to the other piston, if three feet in diameter, would be upwards of 40,000 tons; but such a force is much too great for the strength of any material with which we are acquainted.

A small quantity of water, extending to a great elevation, would give the pressure above described, it being only for the sake of convenience, that the forcing pump is employed, instead of a column of water.

There is no doubt, but in the operations of nature, great effects are sometimes produced among mountains, by a small quantity of water finding its way to a reservoir in the crevices of the rocks far beneath.

Fig. 85.



Suppose, in the interior of a mountain, fig. 85, there should be a space of 10 yards square, and an inch deep, filled with water, and closed up on all sides; and suppose that in the course of time, a small fissure, no more than an inch in diameter, should be opened by the water, from the height of two hundred feet above, down to this little reservoir. The consequence might be, that the side of the mountain would burst asunder, for the pressure, under the circumstances supposed, would be equal to the weight of five thousand tons.

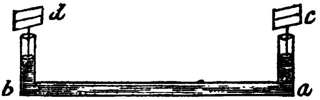
What is the estimated force which a man could give by one of these engines? If the pressure of two tons be made on a piston of a quarter of an inch in diameter, what will be the force transmitted to the other piston of three feet in diameter? What is said of the pressure of water in the crevices of mountains, and the consequences?

Water Level.

We have seen, that in whatever situation water is placed, it always tends to seek a *level.* Thus, if several vessels communicating with each other be filled with water, the fluid will be at the same height in all, and the level will be indicated by a straight line drawn through all the vessels, as in fig. 80.

It is on the principle of this tendency, that the little instrument called the *water level* is constructed.

Fig. 86.

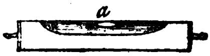


The form of this instrument is represented by fig. 86. It consists of *a*, *b*, a tube, with its two ends turned at right angles, and left open. Into one of the ends is poured water or mercury, until the fluid rises a little in the angles of the tube. On the surface of the fluid, at each end, are then placed small floats, carrying upright frames, across which are drawn small wires or hairs, as seen at *c* and *d*. These hairs are called the *sights*, and are across the line of the tube.

It is obvious that this instrument will always indicate a level, when the floats are at the same height, in respect to each other, and not in respect to their comparative heights in the ends of the tube, for if one end of the instrument be held lower than the other, still the floats must always be at the same height. To use this level, therefore, we have only to bring the two sights, so that one will range with the other; and on placing the eye at *c*, and looking towards *d*, this is determined in a moment.

This level is indispensable in the construction of canals and aqueducts, since the engineer depends entirely on it, to ascertain whether the water can be carried over a given hill or mountain.

Fig. 87.



The common *spirit level* consists of a glass tube, fig. 87, filled with spirit of wine, excepting a small space in which there is left a bubble of air. This bubble, when the instrument is laid on

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On what principle is the water-level constructed? Describe the manner in which the level with sights is used, and the reason why the floats will always be at the same height. What is the use of the level? Describe the common spirit level, and the method of using it.

a level surface, will be exactly in the middle of the tube, and therefore to adjust a level, it is only necessary to bring the bubble to this position.

The glass tube is enclosed in a brass case, which is cut out on the upper side, so that the bubble may be seen, as represented in the figure.

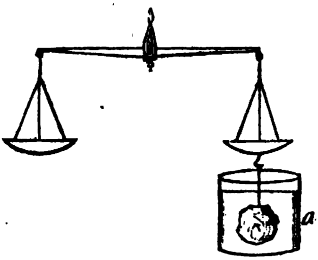
This instrument is employed by builders to level their work, and is highly convenient for that purpose, since it is only necessary to lay it on a beam to try its level.

Specific Gravity.

If a tumbler be filled with water to the brim, and an egg, or any other heavy solid, be dropped into it, a quantity of the fluid, exactly equal to the size of the egg, or other solid, will be displaced, and will flow over the side of the vessel. Bodies which sink in water, therefore, displace a quantity of the fluid equal to their own bulks.

Now, it is found, by experiment, that when any solid substance sinks in water, it loses, while in the fluid, a portion of its weight, just equal to the weight of the bulk of water which it displaces. This is readily made evident by experiment.

Fig. 88.



Take a piece of ivory, or any other substance that will sink in water, and weigh it accurately in the usual manner; then suspend it by a thread, or hair, in the empty cup *a*, fig. 88, and then balance it, as shown in the figure. Now pour water into the cup, and it will be found that the suspended body will lose a part of its weight, so that a certain number of grains must be taken from the opposite scale, in order to make the scales balance as before the water was poured in. The number of grains taken from the opposite scale, show the weight of a quantity of water equal to the bulk of the body so suspended.

When a solid is weighed in water, why does it lose a part of its weight? How much less will a cubic inch of any substance weigh in water than in air? How is it proved by fig. 88, that a body weighs less in water than in air? What is the specific gravity of a body? How are the specific gravities of solid bodies taken?

It is on the principle, that bodies weigh less in the water, than they do when weighed out of it, or in the air, that water becomes the means of ascertaining their specific gravities, for it is by comparing the weight of a body in the water, with what it weighs out of it, that its specific gravity is determined.

Thus, suppose a cubic inch of gold weighs 19 ounces, and on being weighed in water, weighs only 18 ounces, or loses a nineteenth part of its weight, it will prove that gold, bulk for bulk, is nineteen times heavier than water, and thus 19 would be the specific gravity of gold. And so if a cube of copper weigh 9 ounces in the air, and only 8 ounces in the water, then copper, bulk for bulk, is 9 times as heavy as water, and therefore has a specific gravity of 9.

If the body weigh less, bulk for bulk, than water, it is obvious that it will not sink in it, and therefore weights must be added to the lighter body, to ascertain how much less it weighs than water.

The specific gravity of a body, then, is merely its weight, compared with the same bulk of water; and water is thus made the standard by which the weights of all other bodies are compared.

To take the specific gravity of a solid which sinks in water, first weigh the body in the usual manner, and note down the number of grains it weighs. Then with a hair, or fine thread, suspend it from the bottom of the scale-dish, in a vessel of water, as represented by fig. 88. As it weighs less in water, weights must be added to the side of the scale where the body is suspended, until they exactly balance each other. Next note down the number of grains so added, and they will show the difference between the weight of the body in air, and in water.

It is obvious, that the greater the specific gravity of the body, the less, comparatively, will be this difference, because each body displaces only its own bulk of water, and some bodies of the same bulk, will weigh many times as much as others.

For example, we will suppose that a piece of platina, weighing 22 ounces, will displace an ounce of water, while a piece of silver, weighing 22 ounces, will displace two ounces of water. The platina, therefore, when suspended as above described, will require one ounce to make the scales balance,

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Why does a heavy body weigh comparatively less in the water than a light one?

while the same weight of silver will require two ounces for the same purpose. The platina, therefore, bulk for bulk, will weigh twice as much as the silver, and will have twice as much specific gravity.

Having noted down the difference between the weight of the body in air and in water, as above explained, the specific gravity is found by dividing the weight in air, by the loss in water. The greater the loss, therefore, the less will be the specific gravity, the bulk being the same.

Thus, in the above example, 22 ounces of platina was supposed to lose one ounce in water, while 22 ounces of silver lost two ounces in water. Now 22, divided by 1, the loss of the platina, is 22; and 22 divided by 2, the loss in the silver, is 11. So that the specific gravity of platina is 22, while that of silver is 11. The specific gravities of these metals, are, however, a little less than here estimated. [*For other methods of taking specific gravity, see Chemistry.*]

Hydrometer.

The *hydrometer* is an instrument, by which the specific gravities of fluids are ascertained, by the depth to which it sinks below their surfaces.

Suppose a cubic inch of lead loses, when weighed in water, 253 grains, and when weighed in alcohol, only 209 grains, then, according to the principle already recited, a cubic inch of water actually weighs 253, and a cubic inch of alcohol 209 grains, for when a body is weighed in a fluid, it loses just the weight of the fluid it displaces.

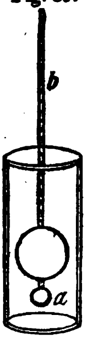
Water, as we have already seen, is the standard by which the weights of other bodies are compared, and by ascertaining what a given bulk of any substance weighs in water, and then what it weighs in any other fluid, the comparative weight of water and this fluid will be known. For if, as in the above example, a certain bulk of water weighs 253 grains, and the same bulk of alcohol only 209 grains, then alcohol has a specific gravity, nearly one fourth less than water.

It is on this principle that the hydrometer is constructed.

Having taken the difference between the weight of a body in air and in water, by what rule is its specific gravity found? Give the example stated, and show how the difference between the specific gravities of platina and silver is ascertained. What is the hydrometer? Suppose a cubic inch of any substance weighs 253 grains less in water than in air, what is the actual weight of a cubic inch of water? On what principle is the hydrometer founded?

It is composed of a hollow ball of glass, or metal, with a graduated scale rising from its upper part, and a weight on its under part, which serves to balance it in the fluid.

Fig. 89.



Such an instrument is represented by fig. 89, of which *b* is the graduated scale, and *a* the weight, the hollow ball being between them.

To prepare this instrument for use, weights, in grains, or half grains, are put into the little ball *a*, until the scale is carried down, so that a certain mark on it coincides exactly with the surface of the water. This mark then becomes the standard of comparison between water and any other liquid, in which the hydrometer is placed. If plunged into a fluid lighter than water, it will sink, and consequently the fluid will rise higher on the scale. If the fluid is heavier than water, the scale will rise above the surface in proportion, and thus it is ascertained, in a moment, whether any fluid has a greater or less specific gravity than water.

To know precisely how much the fluid varies from the standard, the scale is marked off into degrees, which indicate grains by weight, so that it is ascertained, very exactly, how much the specific gravity of one fluid differs from that of another.

Water being the standard by which the weights of other substances are compared, it is placed as the unit, or point of comparison, and is therefore 1, 10, 100, or 1000, the ciphers being added whenever there are fractional parts expressing the specific gravity of the body. It is always understood, therefore, that the specific gravity of water is 1, and when it is said a body has a specific gravity of 2, it is only meant, that such a body is, bulk for bulk, twice as heavy as water. If the substance is lighter than water, it has a specific gravity of 0, with a fractional part. Thus alcohol has a specific gravity of 0,809, that is 809, water being 1000.

How is this instrument formed? How is the hydrometer prepared for use? How is it known, by this instrument, whether the fluid is lighter or heavier then water? What is the standard by which the weights of other bodies are compared? What is the specific gravity of water? When it is said that the specific gravity of a body is 2 or 4, what meaning is intended to be conveyed?

By means of this instrument, it can be told with great accuracy how much water has been added to spirits, for the greater the quantity of water, the higher will the scale rise above the surface.

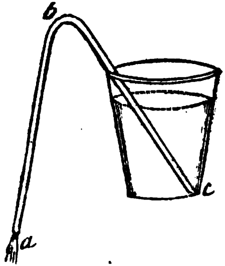
The adulteration of milk with water, can also be readily detected with it, for as new milk has a specific gravity of 1032, water being 1000, a very small quantity of water mixed with it would be indicated by the instrument. (*See Specific Gravity in Chemistry.*)

The Syphon.

Take a tube, bent like the letter U, and having filled it with water, place a finger on each end, and in this state plunge one of the ends into a vessel of water, so that the end in the water shall be a little the highest, then remove the fingers, and the liquid will flow out, and continue to do so, until the vessel is exhausted.

A tube acting in this manner, is called a *syphon*, and is represented by fig. 90. The reason why the water flows from the end of the tube *a*, and consequently ascends through the other part, is, that there is a greater weight of the fluid from *b* to *a*, than from *c* to *b*, because the perpendicular height from *b* to *a* is the greatest. The weight of the water from *b* to *a* falling downwards, by its gravity, tends to form a vacuum, or void space, in that leg of the tube; but the pressure of the atmosphere on the water in the vessel, constantly forces the fluid up the other leg of the tube, to fill the void space, and thus the stream is continued as long as any water remains in the vessel.

Fig. 90.



The action of the syphon depends upon the same principle as the action of the pump, namely, the pressure of the atmosphere, and therefore its explanation properly belongs to Pneumatics. It is introduced here merely for the purpose of illustrating the phenomena of intermitting springs; a subject which properly belongs to Pneumatics.

Alcohol has a specific gravity of 809; what, in reference to this, is the specific gravity of water? In what manner is a syphon made? Explain the reason why the water ascends through one leg of the syphon, and descends through the other.

Some springs, situated on the sides of mountains, flow for a while with great violence, and then cease entirely. After a time they begin to flow again, and then suddenly stop, as before. These are called *intermitting springs*. Among ignorant and superstitious people, these strange appearances have been attributed to witchcraft, or the influence of some supernatural power. But an acquaintance with the laws of nature will dissipate such ill founded opinions, by showing that they owe their peculiarities to nothing more than natural syphons, existing in the mountains from whence the water flows.

Fig. 91.

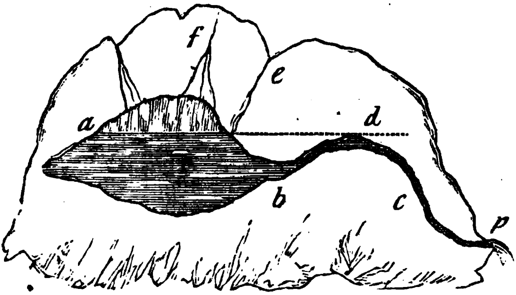


Fig. 91 is the section of a mountain and spring, showing how the principle of the syphon operates to produce the effect described. Suppose there is a crevice, or hollow in the rock, from *a* to *b*, and a narrow fissure leading from it, in the form of the syphon *b c*. The water, from the rills *f*, *e*, filling the hollow, up to the line *a d*, it will then discharge itself through the syphon, and continue to run until the water is exhausted down to the leg of the syphon *b*, when it will cease. Then the water from the rills continuing to run until the hollow is again filled up to the same line, the syphon again begins to act, and again discharges the contents of the reservoir as before, and thus the spring *p*, at one moment, flows with great violence, and the next moment ceases entirely.

The hollow, above the line *a d*, is supposed not to be filled with the water at all, since the syphon begins to act whenever the fluid rises up to the bend *d*.

What is an intermitting spring? How is the phenomenon of the intermitting spring explained? Explain fig. 91, and show the reason why such a spring will flow, and cease to flow, alternately.

During the dry seasons of the year, it is obvious, that such a spring would cease to flow entirely, and would begin again only when the water from the mountain filled the cavity through the rills.

Such springs, although not very common, exist in various parts of the world. Dr. Atwell has described one in the Philosophical Transactions, which he examined in Devonshire, in England. The people in the neighborhood, as usual, ascribed its actions to some sort of witchery, and advised the doctor, in case it did not ebb and flow readily, when he and his friend were both present, that one of them should retire, and see what the spring would do, when only the other was present.

HYDRAULICS.

It has been stated, that Hydrostatics is that branch of Natural Philosophy, which treats of the weight, pressure, and equilibrium of fluids, and that Hydraulics has for its object the investigation of the laws which regulate fluids in motion.

If the pupil has learned the principles on which the pressure and equilibrium of fluids depend, as explained under the former article, he will now be prepared to understand the laws which govern fluids when in motion.

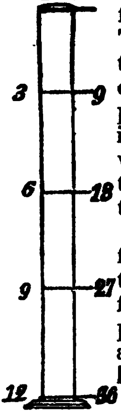
The pressure of water downwards, is exactly in the same proportion to its height, as is the pressure of solids in the same direction.

Suppose a vessel of three inches in diameter has a billet of wood set up in it, so as to touch only the bottom, and suppose the piece of wood to be three feet long, and to weigh nine pounds; then the pressure on the bottom of the vessel will be nine pounds. If another billet of wood be set on this, of the same dimensions, it will press on its top with the weight of nine pounds, and the pressure at the bottom will be 18 pounds, and if another billet be set on this, the pressure at the bottom will be 27 pounds, and so on, in this ratio, to any height the column is carried.

Now the pressure of fluids is exactly in the same proportion; and when confined in pipes, may be considered as one short column set on another, each of which increases the pressure of the lowest, in proportion to their number and height.

How does the science of Hydrostatics differ from that of Hydraulics? Does the downward pressure of water differ from the downward pressure of solids, in proportion? How is the downward pressure of water illustrated?

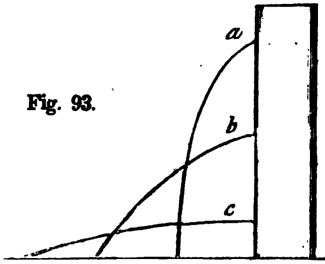
Fig. 92.



Thus, notwithstanding the lateral pressure of fluids, their downward pressure is as their heights. This fact will be found of importance in the investigation of the principles of certain hydraulic machines, and we have therefore endeavoured to impress it on the mind of the pupil by fig. 92. where it will be seen, that if the pressure of three feet of water be equal to nine pounds on the bottom of the vessel, the pressure of twelve feet will be equal to thirty-six pounds.

The quantity of water which will be discharged from an orifice of a given size, will be in proportion to the height of the column of water above it, for the discharge will increase in velocity, in proportion to the pressure, and the pressure, we have already seen, will be in a fixed ratio to the height.

Fig. 93.



If a vessel, fig. 93, be filled with water, and three apertures be made in its side at the points *a*, *b*, and *c*, the fluid will be thrown out in jets, and will fall towards the earth, in the curved lines, *a*, *b*, and *c*. The reason why these curves differ in shape, is, that the fluid is acted on by two forces, namely, the pressure of the water above the jet, which produces its velocity forward, and the action of gravity, which impels it downward. It therefore obeys the same laws that solids do when projected forward, and falls down in curved lines, the shapes of which depend on their relative velocities.

The quantity of water discharged, being in proportion to the pressure, that discharged from each orifice will differ in quantity according to the height of the water above it.

It is found, however, that the velocity with which a vessel

Without reference to the lateral pressure, in what proportion do fluids press downwards? What will be the proportion of a fluid discharged from an orifice of a given size? Why do the lines described by the jets from the vessel, fig. 93, differ in shape?

discharges its contents, does not depend entirely on the pressure, but in part on the kind of orifice through which the liquid flows. It might be expected, for instance, that a tin vessel of a given capacity, with an orifice of say an inch in diameter through its side, would part with its contents sooner than another of the same capacity and orifice, whose side was an inch or two thick, since the friction through the tin might be considered much less than that presented by the other orifice. But it has been found by experiment, that the tin vessel does not part with its contents so soon as another vessel, of the same height and size of orifice, from which the water flowed through a short pipe. And, on varying the length of these pipes, it is found that the most rapid discharge, other circumstances being equal, is through a pipe, whose length is twice the diameter of its orifice. Such an aperture discharged 82 quarts, in the same time that another vessel of tin without the pipe, discharged 62 quarts.

This surprising difference is accounted for, by supposing that the cross currents, made by the rushing of the water from different directions towards the orifice, mutually interfere with each other, by which the whole is broken, and thrown into confusion by the sharp edge of the tin, and hence the water issues in the form of spray, or of a screw, from such an orifice. A short pipe seems to correct this contention among opposing currents, and to smooth the passage of the whole, and hence we may observe, that from such a pipe, the stream is round and well defined.

Friction between solids and fluids.

The rapidity with which water flows through pipes of the same diameter, is found to depend much on the nature of their internal surfaces. Thus, a lead pipe with a smooth aperture, under the same circumstances, will convey much more water than one of wood, where the surface is rough, or beset with points. In pipes, even where the surface is as smooth as

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What two forces act upon the fluid as it is discharged, and how do these forces produce a curved line? Does the velocity with which a fluid is discharged, depend entirely on the pressure? What circumstance, besides pressure, facilitates the discharge of water from an orifice? In a tube discharging water with the greatest velocity, what is the proportion between its diameter and its length? What is the proportion between the quantity of fluid discharged through an orifice of tin, and through a short pipe? Suppose a lead and a glass tube, of the same diameter, which will deliver the greatest quantity of liquid in the same time?

glass, there is still considerable friction, for in all cases the water is found to pass more rapidly in the middle of the stream than it does on the outside, where it rubs against the sides of the tube.

The sudden turns, or angles of a pipe, are also found to be a considerable obstacle to the rapid conveyance of the water, for such angles throw the fluid into eddies or currents, by which its velocity is arrested.

In practice, therefore, sudden turns are generally avoided, and where it is necessary that the pipe should change its direction, it is done by means of as large a circle as convenient.

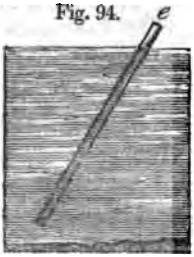
Where it is proposed to convey a certain quantity of water to a considerable distance in pipes, there will be a great disappointment in respect to the quantity actually delivered, unless the engineer takes into account the friction, and the turnings of the pipes, and makes large allowances for these circumstances. If the quantity to be actually delivered ought to fill a two inch pipe, one of three inches will not be too great an allowance, if the water is to be conveyed to any considerable distance.

In practice, it will be found that a pipe of two inches in diameter, one hundred feet long, will discharge about five times as much water as one of one inch in diameter of the same length, and under the same pressure. This difference is accounted for, by supposing that both tubes retard the motion of the fluid, by friction, at equal distance from their inner surfaces, and consequently, that the effect of this cause is much greater in proportion, in the small tube, than in the large one.

The effect of friction in retarding the motion of fluids is perpetually illustrated in the flowing of rivers and brooks. On the side of a river, the water, especially where it is shallow, is nearly still, while in the middle of the stream it may run at the rate of five or six miles an hour. For the same reason, the water at the bottoms of rivers is much less rapid than at the surface. This is often proved by the oblique position of floating substances, which in still water would assume a vertical direction.

Why will the glass tube deliver most? What is said of the sudden turnings of a tube in retarding the motion of the fluid? How much more water will a two inch tube of a hundred feet long discharge, than a one inch tube of the same length? How is this difference accounted for? How do rivers show the effect of friction in retarding the motion of their waters?

Fig. 94.



Thus, suppose the stick of wood *e*, fig. 94, to be loaded at one end with lead, of the same diameter as the wood, so as to make it stand upright in still water. In the current of a river, where the lower end nearly reaches the bottom, it will incline as in the figure, because the water is more rapid towards the surface than at the bottom, and hence the tendency of the upper end to move faster than the lower one, gives it an inclination forward.

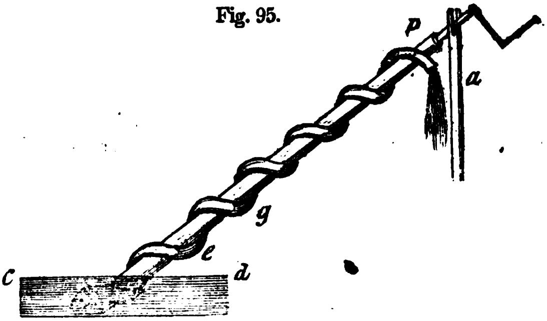
Machines for raising water.

The common pump, though a hydraulic machine, depends on the pressure of the atmosphere for its effect, and therefore its explanation comes properly under the article Pneumatics, where the consequences of atmospheric pressure will be illustrated.

Such machines only, as raise water without the assistance of the atmosphere, come properly under the present article.

Among these, one of the most curious, as well as ancient machines, is the *screw of Archimedes*, and which was invented by that celebrated philosopher, two hundred years before the Christian era, and then employed for raising water and draining land in Egypt.

Fig. 95.



In consists of a large tube, fig. 95, coiled around a shaft of wood to keep it in place, and give it support. Both ends of

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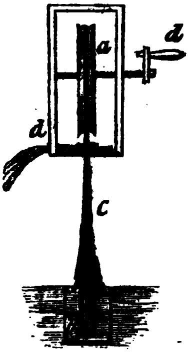
Explain fig. 94. Who is said to have been the inventor of Archimedes' screw? Explain this machine, as represented in fig. 95, and show how the water is elevated by turning it.

the tube are open, the lower one being dipped into the water to be raised, and the upper one discharging it in an intermitting stream. The shaft turns on a support at each end, that at the upper end being seen at *a*, the lower one being hid by the water. As the machine now stands, the lower bend of the screw is filled with water, since it is below the surface *c*, *d*. On turning it by the handle, from left to right, that part of the screw now filled with water will rise above the surface *c*, *d*, and the water having no place to escape, falls into the next lowest part of the screw at *e*. At the next revolution, that portion which, during the last was at *e*, will be elevated to *g*, for the lowest bend will receive another supply, which in the mean time will be transferred to *e*, and thus by a continuance of this motion, the water is finally elevated to the discharging orifice *p*.

This principle is readily illustrated by winding a piece of lead tube round a walking stick, and then turning the whole with one end in a dish of water, as shown in the figure.

Fig. 96.



Instead of this method, water was sometimes raised by the ancients, by means of a rope, or bundle of ropes, as shown at fig. 96.

This mode illustrates in a very striking manner the force of friction between a solid and fluid, for it was by this force alone, that the water was supported and elevated.

The large wheel *a*, is supposed to stand over the well, and *b*, a smaller wheel, is fixed in the water. The rope is extended between the two wheels, and rises on one side in a perpendicular direction. On turning the wheel by the crank *d*, the water is brought up by the friction of the rope, and falling into a reservoir at the bottom of the frame which supports the wheel, is discharged at the spout *d*.

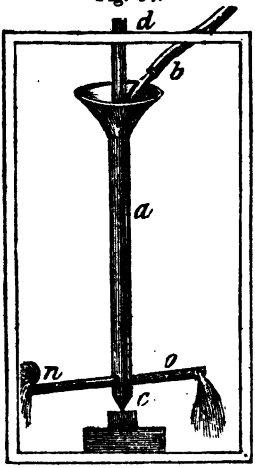
It is evident that the motion of the wheel, and consequently that of the rope, must be very rapid, in order to raise any considerable quantity of water by this method. But when the upward velocity of the rope is eight or ten feet per second, a large quantity of water may be elevated to a considerable height by this machine.

For the different modes of applying water as a power for

How may the principle of Archimedes' screw be readily illustrated? Explain in what manner water is raised by the machine represented by fig. 96.

driving mills, and other useful purposes, we must refer the reader to works on practical mechanics. There is, however, one method of turning machinery by water, invented by Dr Barker, which is strictly a philosophical, and at the same time a most curious invention, and therefore is properly introduced here.

Fig. 97.



This machine is called *Barker's centrifugal mill*, and such parts of it as are necessary to understand the principle on which it acts are represented by fig. 97.

The upright cylinder *a*, is a tube which has a funnel-shaped mouth, for the admission of the stream of water from the pipe *b*. This tube is six or eight inches in diameter, and may be from ten to twenty feet long. The arms *n* and *o*, are also tubes communicating freely with the upright one, from the opposite sides of which they proceed. The shaft *d*, is firmly fastened to the inside of the tube, openings at the same time being left for the water to pass to the arms *o* and *n*. The lower part of the tube is solid, and turns on a point resting on the block of stone or iron, *c*. The arms are closed at their ends, near which there are orifices on the sides opposite to each other, so that the water spouting from them, will fly in opposite directions. The stream from the pipe *b*, is regulated by a stopcock, so as to keep the tube *a* constantly full without overflowing.

To set this engine in motion, suppose the upright tube to be filled with water, and the arms *n* and *o*, to be given a slight impulse; the pressure of the water from the perpendicular column in the large tube will give the fluid a velocity of discharge at the ends of the arms proportionate to its height. The reaction that is produced by the flowing of the water on the points behind the discharging orifice, will continue, and increase the rotatory motion thus begun. After a few revolutions, the machine will receive an additional impulse by the centrifugal force generated in the arms, and

What is fig. 97 intended to represent? Describe this mill.

in consequence of this, a much more violent and rapid discharge of the water takes place, than would occur by the pressure of that in the upright tube alone. The centrifugal force and the force of the discharge thus acting at the same time, and each increasing the force of the other, this machine revolves with great velocity and proportionate power. The friction which it has to overcome, when compared with that of other machines, is very slight, being chiefly at the point *c*, where the weight of the upright tube and its contents is sustained.

By fixing a cog wheel to the shaft at *d*, motion may be given to any kind of machinery required.

Where the quantity of water is small, but its height considerable, this machine may be employed to great advantage, it being under such circumstances one of the most powerful engines ever invented.

PNEUMATICS.

The term Pneumatics is derived from the Greek *pneuma*, which signifies *breath*, or *air*. It is that science which investigates the mechanical properties of air, and other elastic fluids.

Under the article *hydraulics*, it was stated that fluids were of two kinds, namely, *elastic* and *non-elastic*, and that air and the gases belonged to the first kind, while water and other liquids belonged to the second.

The atmosphere which surrounds the earth, and in which we live, and a portion of which we take into our lungs at every breath, is called *air*, while the artificial products which possess the same mechanical properties, are called *gases.*

When, therefore, the word *air* is used, in what follows, it will be understood to mean the atmosphere which we breathe.

Every hollow, crevice, or pore, in solid bodies not filled with a liquid, or some other substance, appears to be filled with air: thus, a tube of any length, the bore of which is as small as it can be made, if kept open, will be filled with air; and hence, when it is said that a vessel is filled with air, it is only meant that the vessel is in its ordinary state. Indeed, this fluid finds its way into the most minute pores of all substances, and cannot be expelled and kept out of any vessel, without the assistance of the air pump, or some other mechanical means.

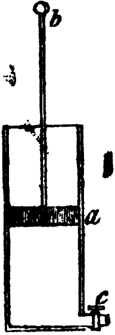
What is pneumatics? What is air? What is gas? What is meant when it is said that a vessel is filled with air? Is there any difficulty in expelling the air from vessels?

By the *elasticity* of air, is meant its spring, or the force with which it re-acts when compressed in a close vessel. It is chiefly in respect to its elasticity and lightness, that the mechanical properties of air differ from those of water and other liquids.

Elastic fluids differ from each other in respect to the *permanency* of the elastic property. Thus, steam is elastic only while its heat is continued, and on cooling returns again to the form of water.

Some of the gases also, on being strongly compressed, lose their elasticity, and take the form of liquids. But air differs from these, in being permanently elastic; that is, if it be compressed with ever so much force, and retained under compression for any length of time, it does not therefore lose its elasticity, or disposition to regain its former bulk, but always re-acts with a force in proportion to the power by which it is compressed.

Fig. 98.



Thus, if the strong tube, or barrel, fig. 98, be smooth, and equal on the inside, and there be fitted to it the solid piston, or plug *a*, so as to work up and down air tight, by the handle *b*, the air in the barrel may be compressed into a space a hundred times less than its usual bulk. Indeed, if the vessel be of sufficient strength, and the force employed sufficiently great, its bulk may be lessened a thousand times, or in any proportion, according to the force employed; and if kept in this state for years it will regain its former bulk the instant the pressure is removed.

Thus, it is a general principle in pneumatics, that air is compressible in proportion to the force employed.

On the contrary, when the usual pressure of the atmosphere is removed from a portion of air, it expands and occupies a space larger than before; and it is found by experiment that this expansion is in a ratio, as the removal of the pressure is more or less complete. Air also expands or increases in bulk when heated.

If the stop-cock *c*, fig. 98, be opened, the piston *a* may be pushed down with ease, because the air contained in the barrel will be forced out at the aperture. Suppose the piston to be

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What is meant by the elasticity of air? How does air differ from steam, and some of the gases, in respect to its elasticity? Does air lose its elastic force by being long compressed? In what proportion to the force employed is the bulk of air lessened?

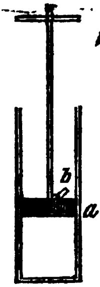
pushed down to within an inch of the bottom, and then the stop-cock closed, so that no air can enter below it. Now, on drawing the piston up to the top of the barrel, the inch of air will expand and fill the whole space, and were this space a thousand times as large, it would still be filled with the expanded air, because the piston removes the pressure of the external atmosphere from that within the barrel.

It follows, therefore, that the space which a given portion of air occupies, depends entirely on circumstances. If it is under pressure, its bulk will be diminished in exact proportion, and as the pressure is removed, it will expand in proportion, so as to occupy a thousand, or even a million times as much space as before.

Another property which air possesses is weight, or gravity. This property, it is obvious, must be slight, when compared with the weight of other bodies. But that air has a certain degree of gravity, in common with other ponderous substances, is proved by direct experiment. Thus, if the air be pumped out of a close vessel, and then the vessel be exactly weighed, it will be found to weigh more when the air is again admitted.

It is, however, the weight of the atmosphere which presses on every part of the earth's surface, and in which we live and move, as in an ocean, that here particularly claims our attention.

Fig. 99.



The pressure of the atmosphere may be easily shown by the tube and piston, fig. 99. Suppose there is an orifice to be opened or closed by the valve *b*, as the piston *a* is moved up or down in its barrel. The valve being fastened by a hinge on one side, on pushing the piston down, it will open by the pressure of the air against it, and the air will make its escape. But when the piston is at the bottom of the barrel, on attempting to raise it again, towards the top, the valve is closed by the force of the external air acting upon it. If, therefore, the piston be drawn up in this state, it must be against the pressure of the atmosphere, the whole weight of which. to an extent equal to the diameter

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In what proportion will a quantity of air increase in bulk as the pressure is removed from it? How is this illustrated by fig. 98? On what circumstance, therefore, will the bulk of a given portion of air depend? How is it proved that air has weight? Explain in what manner the pressure of the atmosphere is shown by fig. 99.

of the piston must be lifted, while there will remain a vacuum or void space below it in the tube. If the piston be only three inches in diameter, it will require the full strength of a man to draw it to the top of the barrel, and when raised, if suddenly let go, it will be forced back again by the weight of the air, and will strike the bottom with great violence.

Supposing the surface of a man to be equal to 14 square feet, and allowing the pressure on each square inch to be 15lbs. such a man would sustain a pressure on his whole surface equal to nearly 14 tons.

Now, that it is the weight of the atmosphere which presses the piston down, is proved by the fact, that if its diameter be enlarged, a greater force, in exact proportion, will be required to raise it. And further, if when the piston is drawn to the top of the tube, a stop-cock, as at fig. 98, be opened, and the air admitted under it, the piston will not be forced down in the least, because then the air will press as much on the under, as on the upper side of the piston.

By accurate experiments, an account of which it is not necessary here to detail, it is found that the weight of the atmosphere on every inch square of the surface of the earth is equal to fifteen pounds. If, then, a piston working air tight in a barrel, be drawn up from its bottom, the force employed besides the friction, will be just equal to that required to lift the same piston, under ordinary circumstances, with a weight laid on it equal to fifteen pounds for every square inch of surface.

The number of square inches in the surface of a piston of a foot in diameter, is 113. This being multiplied by the weight of the air on each inch, which being 15 pounds, is equal to 1695 pounds. Thus the air constantly presses on every surface, which is equal to the dimensions of a circle one foot in diameter, with a weight of 1695 pounds.

Air Pump.

The *air pump* is an engine by which the air can be pumped out of a vessel, or withdrawn from it. The vessel so ex

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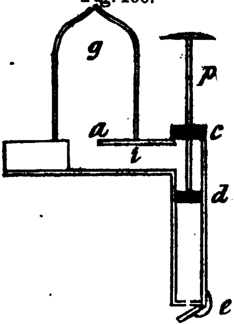
What is the force pressing on the piston when drawn upward, sometimes called? How is it proved that it is the weight of the atmosphere, instead of suction, which makes the piston rise with difficulty? What is the pressure of the atmosphere on every square inch of surface on the earth? What is the number of square inches in a circle of one foot in diameter? What is the weight of the atmosphere on a surface of a foot in diameter?

hausted is called a *receiver*, and the space thus left in the vessel, after withdrawing the air, is called a *vacuum.*

The principles on which the air pump is constructed are readily understood, and are the same in all instruments of this kind, though the form of the instrument itself is often considerably modified.

The general principles of its construction will be comprehended by an explanation of fig. 100. In this figure let *g* be a glass vessel, or receiver, closed at the top, and open at the bottom, standing on a perfectly smooth surface, which is called the *plate* of the air pump. Through the plate is an aperture *a*, which communicates with the inside of the receiver, and the barrel of the pump. The piston rod *p* works air tight through the stuffed collar *c*, and the piston also moves air tight through the barrel. At the extremity of the barrel there is a valve *e*, which opens outwards, and is closed with a spring.

Fig. 100.



Now suppose the piston to be drawn up to *c*, it will then leave a free communication between the receiver *g*, through the orifice *a*, to the pump barrel, in which the piston works. Then if the piston be forced down by its handle, it will compress the air in the barrel between *d* and *e*, and in consequence the valve *e* will be opened, and the air so condensed will be forced out. On drawing the piston up again, the valve will be closed, and the external air not being permitted to enter, a vacuum will be formed in the barrel, from *e* to a little above *d.* When the piston comes again to *c*, the air contained in the glass vessel, together with that in the passage between the vessel and the pump barrel, will rush in to fill the vacuum. Thus, there will be less air in the whole space, and consequently in the receiver, than at first, because all that contained in the barrel is forced out at every stroke of the piston.

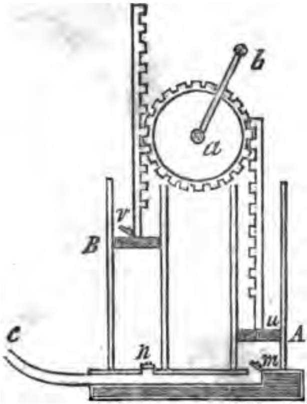
What is the air pump? What is the receiver of an air pump? What is a vacuum? In fig. 100, which is the receiver of the air pump? When the piston is pressed down, what quantity of air is thrown out? When the piston is drawn up, what is formed in the barrel? How is this vacuum again filled with air?

On repeating the same process, that is, drawing up and forcing down the piston, the air at each time in the receiver, will become less and less in quantity, and, in consequence, more and more rarefied. For it must be understood, that although the air is exhausted at every stroke of the pump, that which remains, by its elasticity expands, and still occupies the whole space. The quantity forced out at each successive stroke is, therefore, diminished, until, at last, it no longer has sufficient force before the piston to open the valve, when the exhausting power of the instrument must cease entirely.

Now, it will be obvious, that as the exhausting power of the air pump depends on the expansion of the air within it, a *perfect* vacuum can never be formed by its means, for so long as exhaustion takes place, there must be air to be forced out, and when this becomes so rare as not to force open the valves, then the process must end.

A good air pump has two similar pumping barrels to that described, so that the process of exhaustion is performed in half the time that it could be performed by one barrel.

Fig. 101.



The barrels, with their pistons, and the usual mode of working them, are represented by fig. 101. The piston rods are furnished with racks, or teeth, and are worked by the toothed wheel *a*, which is turned backwards and forwards, by the lever and handle *b*. The exhaustion pipe, *c*, leads to the plate on which the receiver stands, as shown in fig. 100. The valves *v*, *n*, *u*, and *m*, all open upwards.

To understand how these pistons act to exhaust the air from the vessel on the plate, through the pipe *c*, we will suppose, that as the two pistons now stand, the handle *b* is

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Is the air pump capable of producing a perfect vacuum? Why do common air pumps have more than one barrel and piston? How are the pistons of an air pump worked?

to be turned towards the left. This will raise the piston *A*, while the valve *u* will be closed by the pressure of the external air acting on it in the open barrel in which it works. There would then be a vacuum formed in this barrel, did not the valve *m* open and let in the air coming from the receiver through the pipe *c*. When the piston, therefore, is at the upper end of the barrel, the space between the piston and the valve *m*, will be filled with the air from the receiver. Next suppose the handle to be moved to the right, the piston *A* will then descend, and compress the air with which the barrel is filled, which, acting against the valve *u*, forces it open, and thus the air escapes. Thus it is plain, that every time the piston rises, a portion of air, however rarefied, enters the barrel, and every time that it descends, this portion escapes, and mixes with the external atmosphere.

The action of the other piston is exactly similar to this, only that *B* rises while *A* falls, and so the contrary. It will appear, on an inspection of the figure, that the air cannot pass from one barrel to the other, for while *A* is rising, and the valve *m* is open, the piston *B* will be descending, so that the force of the air in the barrel *B*, will keep the valve *n* closed. Many interesting and curious experiments, illustrating the expansibility and pressure of the atmosphere, are shown by this instrument.

If a withered apple be placed under the receiver, and the air is exhausted, the apple will swell and become plump, in consequence of the expansion of the air which it contains within the skin.

Ether placed in the same situation, soon begins to boil without the influence of heat, because its particles, not having the pressure of the atmosphere to force them together, fly off with so much rapidity as to produce ebullition.

The Condenser.

The operation of the *condenser* is the reverse of that of the air pump, and is a much more simple machine. The air pump,

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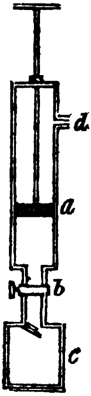
While the piston *A* is ascending, which valves will be open, and which closed? When the piston *A* descends, what becomes of the air with which its barrel was filled? Why does not the air pass from one barrel to the other, through the valves *m* and *n*? Why does an apple placed in the exhausted receiver grow plump? Why does ether boil in the same situation? How does the condenser operate?

as we have just seen, will deprive a vessel of its ordinary quantity of air. The condenser, on the contrary, will double, or treble the ordinary quantity of air in a close vessel, according to the force employed.

Fig. 102.



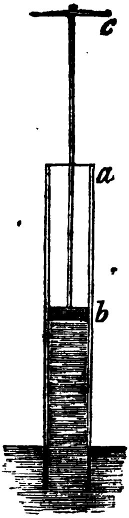
This instrument, fig. 102, consists of a pump barrel and piston *a*, a stop-cock *b*, and the vessel *c* furnished with a valve opening inwards. The orifice *d* is to admit the air, when the piston is drawn up to the top of the barrel.

To describe its action, let the piston be above *d*, the orifice being open, and therefore the instrument filled with air, of the same density as the external atmosphere. Then, on forcing the piston down, the air in the pump barrel, below the orifice *d*, will be compressed, and will rush through the stop-cock *b*, into the vessel *c*, where it will be retained, because, on again moving the piston upward, the elasticity of the air will close the valve through which it was forced. On drawing the piston up again, another portion of air will rush in at the orifice *d*, and on forcing it down, this will also be driven into the vessel *c*; and this process may be continued as long as sufficient force is applied to move the piston, or there is sufficient strength in the vessel to retain the air. When the condensation is finished, the stop-cock *b* may be turned, to render the confinement of the air more secure.

The magazines of *air guns* are filled in the manner above described. The air gun is shaped like other guns, but instead of the force of powder, that of air is employed to project the bullet. For this purpose, a strong hollow ball of copper, with a valve on the inside, is screwed to a condenser, and the air is condensed in it, thirty or forty times. This ball or magazine is then taken from the condenser, and screwed to the gun, under the lock. By means of the lock, a communication is opened between the magazine and the inside of the gun-barrel, on which the spring of the confined air against the leaden bullet is such, as to throw it with nearly the same force as gun-powder.

Explain fig. 102, and show in what manner the air is condensed. Explain the principle of the air gun.

Fig. 103.



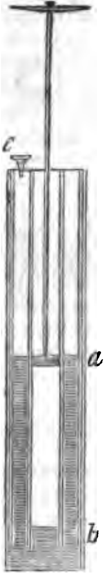
Barometer.

Suppose *a*, fig. 103, to be a long tube with the piston *b*, so nicely fitted to its inside, as to work air tight. If the lower end of the tube be dipped into water, and the piston drawn up by pulling at the handle *c*, the water will follow the piston so closely as to be in contact with its surface, and apparently to be drawn up by the piston, as though the whole was one solid body. If the tube be thirty-five feet long, the water will continue to follow the piston, until it comes to the height of about thirty-three feet, where it will stop, and if the piston be drawn up still farther the water will not follow it, but will remain stationary, the space from this height, between the piston and the water, being left a void space, or vacuum.

The rising of the water in the above case, which only involves the principle of the common pump, is thought by some to be caused by *suction*, the piston *sucking* up the water as it is drawn upward. But according to the common notion attached to this term, there is no reason why the water should not continue to rise above the thirty-three feet, or why the power of suction should cease at that point, rather than at any other. Without entering into any discussion on the absurd notions concerning the power of suction, it is sufficient here to state, that it has long since been proved, that the elevation of the water in the case above described, depends entirely on the weight and pressure of the atmosphere, on that portion of the fluid which is on the outside of the tube. Hence, when the piston is drawn up, under circumstances where the air cannot act on the water around the tube, or pump barrel, no elevation of the fluid will follow. This will be obvious, by the following experiment.

Suppose the tube, fig. 103, to stand with its lower end in the water, and the piston *a* to be drawn upward thirty five feet, how far will the water follow the piston? What will remain in the tube between the piston and the water, after the piston rises higher than thirty-three feet? What is commonly supposed to make the water rise in such cases? Is there any reason why the suction should cease at 33 feet? What is the true cause of the elevation of the water, when the piston, fig. 103, is drawn up?

Fig. 104.



Suppose fig. 104, to be the sections, or **halves** of two tubes, one within the other, the outer one being made entirely close, so as to admit no air, and the space between the two being also made air-tight at the top. Suppose, also, that the inner tube being left open at the lower end, does not reach the bottom of the outer tube, and thus that an open space be left between the two tubes every where, except at their upper ends, where they are fastened together; and suppose that there is a valve in the piston, opening upwards, so as to let the air which it contains, escape, but which will close on drawing the piston upwards. Now let the piston be at *a*, and in this state pour water through the stop cock, *c*, until the inner tube is filled up by the piston, and the space between the two tubes filled up to the same point, and then let the stopcock be closed. If now the piston be drawn up to the top of the tube, the water will not follow it, as in the case first described; it will only rise a few inches, in consequence of the elasticity of the air above the water, between the tubes, and in the space above the water, there will be formed a vacuum between the water and the piston, in the inner tube.

The reason why the result of this experiment differs from that before described, is, that the outer tube prevents the pressure of the atmosphere from forcing the water up the inner tube as the piston rises. This may be instantly proved, by opening the stop-cock *c*, and permitting the air to press upon the water, when it will be found, that as the air rushes in, the water will rise and fill the vacuum, up to the piston.

For the same reason, if a common pump be placed in a cistern of water, and the water is frozen over on the surface, so that no air can press upon the fluid, the piston of the pump might be worked in vain, for the water would not, as usual, obey its motion.

It follows, as a certain conclusion from such experiments, that when the lower end of a tube is placed in water, and the air from within is removed by drawing up the piston, that

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How is it shown by fig. 104, that it is the pressure of the atmosphere which causes the water to rise in the pump barrel? Suppose the ice prevents the atmosphere from pressing on the water in a vessel, can the water be pumped out?

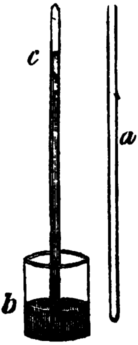
it is the pressure of the atmosphere, on the water around the tube, which forces the fluid up to fill the space, thus left by the air. It is also proved, that the weight, or pressure of the atmosphere, is equal to the weight of a perpendicular column of water 33 feet high, for it is found (fig. 103,) that the pressure of the atmosphere will not raise the water more than 33 feet, though a perfect vacuum be formed to any height above this point. Experiments on other fluids, prove that this is the weight of the atmosphere, for if the end of a tube be dipped in any fluid, and the air be removed from the tube, above the fluid, it will rise to a greater or less height, than water, in proportion as its specific gravity is less or greater than that of water.

Mercury, or *quicksilver*, has a specific gravity of about 13½ times greater than that of water, and mercury is found to rise about 29 inches in a tube under the same circumstances that water rises 33 feet. Now 33 feet is 396 inches, which, being divided by 29, gives nearly 13½, so that mercury being 13½ times heavier than water, the water will rise under the same pressure 13½ times higher than the mercury.

Barometer.

The *barometer* is constructed on the principle of atmospheric pressure, which we have thus endeavoured to explain and illustrate to common comprehension. This term is compounded of two Greek words, *baros*, weight, and *metron*, measure, the instrument being designed to measure the weight of the atmosphere.

Fig. 105.



Its construction is simple, and easily understood, being merely a tube of glass nearly filled with mercury, with its lower end placed in a dish of the same fluid, and the upper end furnished with a scale, to measure the height of the mercury.

Let *a*, fig. 105, be such a tube, 34 or 35 inches long, closed at one end and open at the other. To fill the tube, set it upright, and pour the mercury in at the open end, and

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What conclusion follows from the experiments above described? How is it proved, that the pressure of the atmosphere is equal to the weight of a column of water, 33 feet high? How do experiments on other fluids show that the pressure of the atmosphere is equal to the weight of a column of water 33 feet high? How high does mercury rise in an exhausted tube? What is the principle on which the barometer is constructed? What does the barometer measure?

when it is entirely full, place the fore finger forcibly on this end, and then plunge the tube and finger under the surface of the mercury, before prepared in the cup *b*. Then withdraw the finger, taking care that in doing this, the end of the tube is not raised above the mercury in the cup. When the finger is removed, the mercury will descend four or five inches, and after several vibrations, up and down, will rest at an elevation of 29 or 30 inches above the surface of that in the cup, as at *c*. Having fixed a scale to the upper part of the tube to indicate the rise and fall of the mercury, the barometer would be finished, if intended to remain stationary. It is usual, however, to have the tube inclosed in a mahogany or brass case, to prevent its breaking, and to have the cup closed on the top, and fastened to the tube, so that it can be transported without danger of spilling the mercury.

The cup of the portable barometer also differs from that described, for were the mercury inclosed on all sides, in a cup of wood, or brass, the air would be prevented from acting upon it, and therefore the instrument would be useless. To remedy this defect, and still have the mercury perfectly inclosed, the bottom of the cup is made of leather, which, being elastic, the pressure of the atmosphere acts upon the mercury in the same manner as though it was not inclosed at all. Below the leather bottom there is a round plate of metal an inch in diameter, which is fixed on the top of a screw, so that when the instrument is to be transported, by elevating this piece of metal, the mercury is thrown up to the top of the tube and thus kept from playing backwards and forwards, when the barometer is in motion.

A person not acquainted with the principle of the instrument, on seeing the tube turned bottom upwards, will be perplexed to understand why the mercury does not follow the common law of gravity, and descend into the cup; were the tube of glass 33 feet high, and filled with water, the lower end being dipped into a tumbler of the same fluid, the wonder would be still greater. But as philosophical facts, one is no more wonderful than the other, and both are readily explained by the principles above illustrated.

Describe the construction of the barometer, as represented by fig. 105. How is the cup of the portable barometer made, so as to retain the mercury, and still allow the air to press upon it? What is the use of the metallic plate and screw, under the bottom of the cup? Explain the reason why the mercury does not fall out of the barometer tube, when its open end is downwards.

It has already been shown, that it is the pressure of the atmosphere on the fluid around the tube, by which the fluid within it is forced upward, when the pump is exhausted of its air. The pressure of the air we have also seen, is equal to a column of water 33 feet high, or of a column of mercury 29 inches high. Suppose, then, a tube 33 feet high is filled with water, the air would then be entirely excluded, and were one of its ends closed, and the other end dipped in water, the effect would be the same as though both ends were closed, for the water would not escape, unless the air were permitted to rush in and fill up its place. The upper end being closed, the air could gain no access in that direction, and the open end being under water, is equally secure. The quantity of water in which the end of the tube is placed, is not essential, since the pressure of a column of water an inch in diameter, provided it be 33 feet high, is just equal to a column of air of an inch in diameter, of the whole height of the atmosphere. Hence the water on the outside of the tube serves merely to guard against the entrance of the external air.

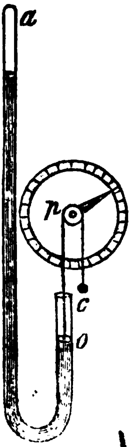
The same happens to the barometer tube, when filled with mercury. The mercury, in the first place, fills the tube perfectly, and therefore entirely excludes the air, so that when it is inverted in the cup, all the space above 29 inches is left a vacuum. The same effect precisely would be produced, were the tube exhausted of its air, and the open end placed in the cup; the mercury would run up the tube 29 inches, and then stop, all above that point being left a vacuum.

The mercury, therefore, is prevented from falling out of the tube, by the pressure of the atmosphere on that which remains in the cup; for if this be removed, the air will enter, while the mercury will instantly begin to descend.

In the barometer described, the rise and fall of the mercury is indicated by a scale of inches and tenths of inches, fixed behind the tube; but it has been found, that very slight variations in the density of the atmosphere, are not readily perceived by this method. It being, however, desirable that these minute changes should be rendered more obvious, a contrivance for increasing the scale, called the *wheel* barometer was invented.

What fills the space above 29 inches, in the barometer tube? In the common barometer how is the rise and fall of the mercury indicated? Why was the wheel barometer invented?

Fig. 106.



The whole length of the tube of the wheel barometer, fig. 106, from *c* to *a*, is 34 or 35 inches, and it is filled with mercury, as usual. The mercury rises in the short leg to the point *o*, where there is a small piece of glass floating on its surface, to which there is attached a silk string, passing over the pulley *p*. To the axis of the pulley is fixed an index, or hand, and behind this is a graduated circle, as seen in the figure. It is obvious, that a very slight variation in the height of the mercury at *o*, will be indicated by a considerable motion of the index, and thus changes in the weight of the atmosphere hardly perceptible by the common barometer, will become quite apparent by this.

The mercury in the barometer tube being sustained by the pressure of the atmosphere, and its medium altitude at the surface of the earth being about 29 inches, it might be expected that if the instrument was carried to a height from the earth's surface, the mercury would suffer a proportionate fall, because the pressure must be less, at a distance from the earth than at its surface, and experiment proves this to be the case. When, therefore, this instrument is elevated to any considerable height, the descent of the mercury becomes perceptible. Even when it is carried to the top of a hill, or high tower, there is a sensible depression of the fluid, so that the barometer is employed to measure the heights of mountains, and the elevation to which balloons ascend from the surface of the earth. On the top of Mont Blanc, which is about 16000 feet above the level of the sea, the medium elevation of the mercury in the tube is only 14 inches, while on the surface of the earth, as above stated, it is 29 inches.

The medium range of the barometer in several countries, has generally been stated to be about 29 inches. It appears, however, from observations made at Cambridge, in Massachusetts, for the term of 22 years, that its range there was nearly 30 inches.

Explain fig. 106, and describe the construction of the wheel barometer. What is stated to be the medium range of the barometer at the surface of the earth? Suppose the instrument is elevated from the earth, what is the effect on the mercury? How does the barometer indicate the heights of mountains? What is the medium range of the mercury on Mont Blanc? What is stated to be the medium range of the barometer at Cambridge?

While the barometer stands in the same place, near the leve. of the sea, the mercury seldom or never falls below 28 inches, or rises above 31 inches, its whole range, while stationary, being only about 3 inches.

These changes in the weight of the atmosphere, indicate corresponding changes in the weather, for it is found, by watching these variations in the height of the mercury, that when it falls, cloudy or falling weather ensues, and that when it rises fine clear weather may be expected. During the time when the weather is damp and lowering, and the smoke of chimnies descends towards the ground, the mercury remains depressed, indicating that the weight of the atmosphere during such weather is less than it is when the sky is clear. This contradicts the common opinion, that the air is the heaviest when it contains the greatest quantity of fog and smoke, and that it is the uncommon weight of the atmosphere which presses these vapours towards the ground. A little consideration will show, that in this case the popular belief is erroneous, for not only the barometer, but all the experiments we have detailed on the subject of specific gravity, tend to show that the lighter any fluid is, the deeper any substance of a given weight will sink in it. Common observation ought, therefore, to correct the error, for every body knows that a heavy body will sink in water while a light one will swim, and by the same kind of reasoning ought to consider, that the particles of vapor would descend through a light atmosphere, while they would be pressed up into the higher regions, by a heavier air.

The principal use of the barometer is on board of ships, where it is employed to indicate the approach of storms, and thus to give an opportunity of preparing accordingly; and it is found that the mercury suffers a most remarkable depression before the approach of violent winds, or hurricanes. The watchful captain, particularly in southern latitudes, is always attentive to this monitor, and when he observes the mercury to sink suddenly, takes his measures without delay to meet the tempest. During a violent storm, we have seen the wheel barometer sink a hundred degrees in a few hours. But we

How many inches does a fixed barometer vary in height? When the mercury falls, what kind of weather is indicated? When the mercury rises, what kind of weather may be expected? When fog and smoke descend towards the ground, is it a sign of a light or heavy atmosphere? By what analogy is it shown that the air is lightest when filled with vapour? Of what use is the barometer, on board of ships? When does the mercury suffer the most remarkable depression?

cannot illustrate the use of this instrument at sea better than to give the following extract from Dr. Arnot, who was himself present at the time. "It was," he says, "in a southern latitude. The sun had just set with a placid appearance, closing a beautiful afternoon, and the usual mirth of the evening watch proceeded, when the captain's orders came to prepare with all haste for a storm. The barometer had begun to fall with appalling rapidity. As yet, the oldest sailors had not perceived even a threatening in the sky, and were surprised at the extent, and hurry of the preparations; but the required measures were not completed, when a more awful hurricane burst upon them, than the most experienced had ever braved. Nothing could withstand it; the sails already furled, and closely bound to the yards, were riven into tatters; even the bare yards and masts were in a great measure disabled; and at one time the whole rigging had nearly fallen by the board. Such, for a few hours, was the mingled roar of the hurricane above, of the waves around, and the incessant peals of thunder, that no human voice could be heard, and amidst the general consternation, even the trumpet sounded in vain. On that awful night, but for a little tube of mercury, which had given the warning, neither the strength of the noble ship, nor the skill and energies of her commander, could have saved one man to tell the tale."

Pumps.

There is a philosophical experiment, of which no one in this country is ignorant. If one end of a straw be introduced into a barrel of cider, and the other end sucked with the mouth, the cider will rise up through the straw, and may be swallowed.

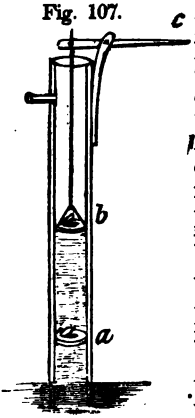
The principles which this experiment involve, are exactly the same as those concerned in raising water by the pump The barrel of cider answers to the well, the straw to the pump log, and the mouth acts as the piston, by which the air is removed.

The efficacy of the common pump, in raising water, depends upon the principle of atmospheric pressure, which has been fully illustrated under the articles *air pump* and *barometer*.

What remarkable instance is stated, where a ship seemed to be saved by the use of the barometer? What experiment is stated, as illustrating the principle of the common pump?

These machines are of three kinds, namely, the *sucking*, or *common* pump, the *lifting* pump, and the *forcing* pump.

Fig. 107.



Of these, the common or household pump is the most in use, and for ordinary purposes, the most convenient. It consists of a long tube, or barrel, called the *pump log*, which reaches from a few feet above the ground to near the bottom of the well. At *a*, fig. 107, is a valve, opening upwards, called the *pump box*. When the pump is not in action, this is always shut. The piston *b*, has an aperture through it, which is closed by a valve, also opening upwards.

By the pupil who has learned what has been explained under the articles air pump, and barometer, the action of this machine will be readily understood.

Suppose the piston *b* to be drawn to *a*, then on depressing the lever *c*, a vacuum would be formed between *a* and *b*, did not the water in the well rise, in consequence of the pressure of the atmosphere on that around the pump log in the well, and take the place of the air thus removed. Then on raising the end of the lever, the valve *a* closes, because the water is forced upon it, in consequence of the descent of the piston, and at the same time the valve in the piston *b* opens, and the water, which cannot descend, now passes above the valve *b*. Next, on raising the piston, by again depressing the lever, this portion of water is lifted up to *b*, or a little above it, while another portion rushes through the valve *a* to fill its place. After a few strokes of the lever, the space from the piston *b* to the spout is filled with the water, where, on continuing to work the lever, it is discharged in a constant stream.

Although, in common language, this is called the suction pump, still it will be observed, that the water is elevated by *suction*, or in more philosophical terms, by atmospheric pressure only above the valve *a*, after which it is raised by *lifting*

On what does the action of the common pump depend? How many kinds of pumps are mentioned? Which kind is the common? Describe the common pump. Explain how the common pump acts. When the lever is depressed, what takes place in the pump barrel? When the lever is elevated, what takes place? How far is the water raised by atmospheric pressure, and how far by lifting?

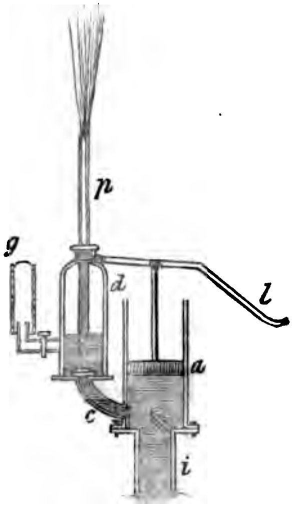
up to the spout. The water, therefore, is pressed into the pump barrel by the atmosphere, and thrown out by lifting.

The *lifting pump*, properly so called, has the piston in the lower end of the barrel, and raises the water through the whole distance, by forcing it upward without the agency of the atmosphere.

In the suction pump, the pressure of the atmosphere will raise the water 33 or 34 feet, and no more, after which it may be lifted to any height required.

The *forcing* pump differs from both these, in having its piston solid, or without a valve, and also in having a side pipe, through which the water is forced, instead of rising in a perpendicular direction, as in the others.

Fig. 108.



The forcing pump is represented by fig. 108, where *a* is a solid piston, working air-tight in its barrel. The tube *c* leads from the barrel of the air vessel *d*. Through the pipe *p* the water is thrown into the open air. *g* is a guage, by which the pressure of the water in the air vessel is ascertained. Through the pipe *i*, the water ascends into the barrel, its upper end being furnished with a valve opening upwards.

To explain the action of this pump, suppose the piston to be down to the bottom of the barrel, and then to be raised upward by the lever *l;* the tendency to form a vacuum in the barrel will bring the water up through the pipe *i*, by the pressure of the atmosphere. Then on depressing the piston, the valve at the bottom of the barrel will be closed, and the water, not finding admittance through the pipe whence it came, will be forced through the pipe *c*, and opening the valve

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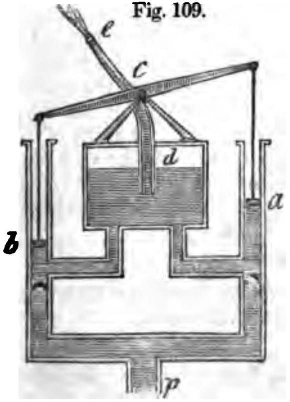
How does the lifting pump differ from the common pump? How does the forcing pump differ from the common pump? Explain fig. 108, and show in what manner the water is brought up through the pipe *i*, and afterwards thrown out at the pipe *p*.

at its upper end, will enter into the air vessel *d*, and be discharged through the pipe *p*, into the open air.

The water is therefore elevated to the piston barrel by the pressure of the atmosphere, and afterwards thrown out by the force of the piston. It is obvious that by this arrangement, the height to which this fluid may be thrown, will depend on the power applied to the lever, and the strength with which the pump is made.

The air vessel *d* contains air in its upper part only, the lower part, as we have already seen, being filled with water. The pipe *p*, called the discharging pipe, passes down into the water so that the air cannot escape. The air is therefore compressed, as the water is forced into the lower part of the vessel, and re-acting upon the fluid by its elasticity, throws it out of the pipe in a continued stream. The constant stream which is emitted from the direction pipe of the fire engine is entirely owing to the compression and elasticity of the air in its air vessel. In pumps without such a vessel, as the water is forced upwards, only while the piston is acting upon it, there must be an interruption of the stream while the piston is ascending, as in the common pump. The air vessel is a remedy for this defect, and is found also to render the labour of drawing the water more easy, because the force with which the air in the vessel acts on the water, is always in addition to that given by the force of the piston.

Fig. 109.



The *fire engine* is a modification of the forcing pump. It consists of two such pumps, the pistons of which are moved by a lever with equal arms, the common fulcrum being at *c*, fig. 109. While the piston *a* is descending, the other piston *b*, is ascending. The water is forced by the pressure of the atmosphere, through the common pipe *p*, and then dividing, ascends into the working barrels of each piston, where the valves, on both sides, prevent its return. By the alternate depression of the pistons, it is then forced into the air box

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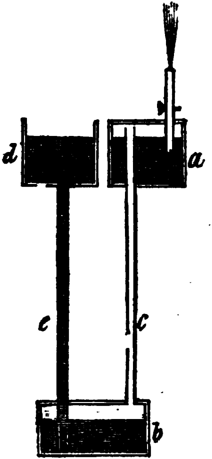
Why does not the air escape from the air vessel in this pump?

d, and then by the direction pipe *e*, is thrown where it is wanted. This machine acts precisely like the forcing pump, only that its power is doubled by having two pistons instead of one.]

Fig. 110.



There is a beautiful fountain, called the *fountain of Hiero*, which acts by the elasticity of the air, and on the same principle as that already described. Its construction will be understood by fig. 110, but its form may be varied according to the dictates of fancy or taste. The boxes *a* and *b*, together with the two tubes, are made air tight, and strong, in proportion to the height it is desired the fountain should play.

To prepare the fountain for action, fill the box *a*, through the spouting tube, nearly full of water. The tube *c*, reaching nearly to the top of the box, will prevent the water from passing downwards, while the spouting pipe will prevent the air from escaping upwards, after the vessel is about half filled with water. Next shut the stop cock, of the spouting pipe, and pour water into the open vessel *d*. This will descend into the vessel *b*, through the tube *e*, which nearly reaches its bottom, so that after a few inches of water are poured in, no air can escape except by the tube *c*, up into the vessel *a*. The air will then be compressed by the weight of the column of water in the tube *e*, and therefore the force of the water from the jet pipe will be in proportion to the height of this tube. If this tube is 20 or 30 feet high, on turning the stop cock, a jet of water will spout from the pipe that will amuse and astonish those who have never before seen such an experiment. [*For other properties of air, see Chemistry.*]

ACOUSTICS.

Acoustics is that branch of natural philosophy which treats of the origin, propagation, and effects of sound.

What effect does the air vessel have on the stream discharged? Why does the air vessel render the labour of raising the water more easy? Explain fig. 109, and describe the action of the fire engine. What causes the continued stream from the direction pipe of this engine? How is the fountain of Hiero constructed?

When a sonorous, or sounding body is struck, it is thrown into a tremulous, or vibrating motion. This motion is communicated to the air which surrounds us, and by the air is conveyed to our ear drums, which also undergo a vibratory motion, and this last motion, throwing the auditory nerves into action, we thereby gain the sensation of sound.

If any sounding body of considerable size, is suspended in the air and struck, this tremulous motion is distinctly visible to the eye, and while the eye perceives its motion, the ear perceives the sound.

That sound is conveyed to the ear by the motion which the sounding body communicates to the air, is proved by an interesting experiment with the air pump. Among philosophical instruments, there is a small bell, the hammer of which is moved by a spring connected with clock-work, and which is made expressly for this experiment.

If this instrument be wound up, and placed under the receiver of an air pump, the sound of the bell may at first be heard to a considerable distance, but as the air is exhausted, it becomes less and less audible, until no longer to be heard, the strokes of the hammer, though seen by the eye, producing no effect upon the ear. Upon allowing the air to return gradually, a faint sound is at first heard, which becomes louder and louder, until as much air is admitted, as was withdrawn.

On the contrary, when the air is more dense than ordinary, or when a greater quantity is contained in a vessel, than in the same space in the open air, the effect of sound on the ear is increased. This is illustrated by the use of the diving bell.

The diving bell is a large vessel, open at the bottom, under which men descend to the beds of rivers, for the purpose of obtaining articles from the wrecks of vessels. When this machine is sunk to any considerable depth, the water above, by its pressure, condenses the air under it with great force. In this situation, a whisper is as loud as a common voice in the open air, and an ordinary voice becomes painful to the ear.

Again, on the tops of high mountains, where the pressure, or density of the air is much less than on the surface of the earth, the report of a pistol is heard only a few rods, and the

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On what will the height of the jet from Hiero's fountain depend? What is acoustics? When a sonorous body is struck within hearing, in what manner do we gain from it the sensation of sound? How is it proved, that sound is conveyed to the ear by the medium of the air? When the air is more dense than ordinary, how does it affect sound?

human voice is so weak as to be inaudible at ordinary distances.

Thus, the atmosphere which surrounds us, is the medium by which sounds are conveyed to our ears, and to its vibrations we are indebted for the sense of hearing, as well as to all we enjoy from the charms of music.

The atmosphere, though the most common, is not, however, the only, or the best conductor of sound. Solid bodies conduct sound better than elastic fluids. Hence, if a person lay his ear on a long stick of timber, the scratch of a pin may be heard from the other end, which could not be perceived through the air.

The earth conducts loud rumbling sounds made below its surface to great distances. Thus, it is said, that in countries where volcanoes exist, the rumbling noise which generally precedes an eruption, is heard first by the beasts of the field, because their ears are commonly near the ground, and that by their agitation and alarm, they give warning of its approach to the inhabitants.

The Indians of our country will discover the approach of horses or men, by laying their ears on the ground, when they are at such distances as not to be heard in any other manner.

Sound is propagated through the air at the rate of 1142 feet in a second of time. When compared with the velocity of light, it therefore moves but slowly. Any one may be convinced of this by watching the discharge of cannon at a distance. The flash is seen apparently at the instant the gunner touches fire to the powder; the whizzing of the ball, if the ear is in its direction, is next heard, and lastly, the report.

Solid substances convey sounds with greater velocity than air, as is proved by the following experiment, lately made at Paris, by M. Biot.

At the extremity of a cylindrical tube, upwards of 3000 feet long, a ring of metal was placed, of the same diameter as the aperture of the tube; and in the centre of this ring, in the mouth of the tube, was suspended a clock bell and hammer. The hammer was made to strike the ring and the bell at the same instant, so that the sound of the ring would be

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What is said of the effects of sound on the tops of high mountains? Which are the best conductors of sound, solid or elastic substances? What is said of the earth as a conductor of sounds? How is it said that the Indians discover the approach of horses? How fast does sound pass through the air? Which convey sounds with the greatest velocity, solid substances, or air?

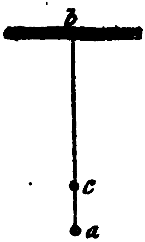
transmitted to the remote end of the tube, through the conducting power of the tube itself, while the sound of the bell would be transmitted through the medium of the air inclosed in the tube. The ear being then placed at the remote end of the tube, the sound of the ring, transmitted by the metal of the tube, was first heard distinctly, and after a short interval had elapsed, the sound of the bell, transmitted by the air in the tube, was heard. The result of several experiments was, that the metal conducted the sound at the rate of about 11,865 feet per second, which is about ten and a half times the velocity with which it is conducted by the air.

Sound moves forward in straight lines, and in this respect follows the same laws as moving bodies, and light. It also follows the same laws in being reflected, or thrown back, when it strikes a solid, or reflecting surface.

If the surface be smooth, and of considerable dimensions, the sound will be reflected, and an *echo* will be heard; but if the surface is very irregular, soft, or small, no such effect will be produced.

In order to hear the echo, the ear must be placed in a certain direction, in respect to the point where the sound is produced, and the reflecting surface.

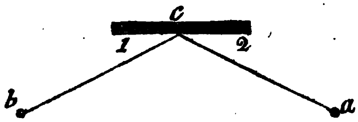
Fig. 111.



If a sound be produced at *a*, fig. 111, and strike the plane surface *b*, it will be reflected back in the same line, and the echo will be heard at *c* or *a*. That is, the angle under which it approaches the reflecting surface, and that under which it leaves it, will be equal.

Whether the sound strikes the reflecting surface at right angles, or obliquely, the angle of approach, and the angle of reflection, will always be the same, and equal.

Fig. 112.

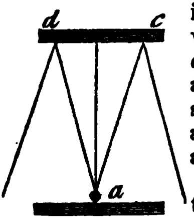


This is illustrated by fig. 112, where suppose a pistol to be fired at *a*, while the reflecting surface is at *c;* then the echo will be heard at *b*, the angles 2 and 1 being equal to each other.

Describe the experiment proving that sound is conducted by a metal with greater velocity than by the air. In what lines does sound move? From what kind of surface is sound reflected, so as to produce an echo? Explain fig. 111.

If a sound be emitted between two reflecting surfaces, parallel to each other, it will reverberate, or be answered backwards and forwards several times.

Fig. 113.

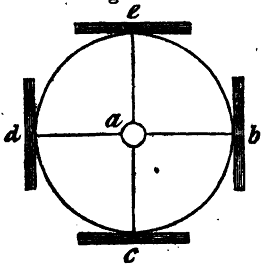


Thus, if the sound be made at *a*, **fig. 113**, it will not only rebound back again to *a*, but will also be reflected from the points *c* and *d*, and were such reflecting surfaces placed at every point around a circle from *a*, the sound would be thrown back from them all, at the same instant, and would meet again at the point *a*.

We shall see under the article Optics, that light observes exactly the same law in respect to its reflection from plane surfaces, and that the angle at which it strikes is called the *angle of incidence*, and that under which it leaves the reflecting surface is called the *angle of reflection*. The same terms are employed in respect to sound.

In a circle, as mentioned above, sound is reflected from every plane surface placed around it, and hence if the sound is emitted from the centre of a circle, this centre will be the point at which the echo will be most distinct.

Fig. 114.

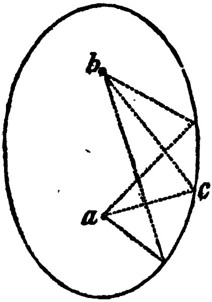


Suppose the ear to be placed at the point *a*, **fig. 114**, in the centre of a circle; and let a sound be produced at the same point, then it will move along the line *a e*, and be reflected from the plane surface, back on the same line to *a*; and this will take place from all the plane surfaces placed around the circumference of a circle; and as all these surfaces are at the same distance from the centre, so the reflected sound will arrive at the point *a*, at the same instant; and the echo will be loud, in proportion to the number and perfection of these reflecting surfaces.

Explain fig. 112, and show in what direction sound approaches and leaves a reflecting surface. What is the angle under which sound strikes a reflecting surface called? What is the angle under which it leaves a reflecting surface called? Is there any difference in the quantity of these two angles? Suppose a pistol to be fired in the centre of a circular room, where would be the echo?

It is apparent that the auditor, in this case, must be placed in the centre from which the sound proceeds, to receive the greatest effect. But if the shape of the room be oval, or elliptical, the sound may be made in one part, and the echo will be heard in another part, because the ellipse has two points, called foci, at one of which, the sound being produced, it will be concentrated in the other.

Fig. 115.



Suppose a sound to be produced at *a*, fig. 115, it will be reflected from the sides of the room, the angles of incidence being equal to those of reflection, and will be concentrated at *b*. Hence a hearer standing at *b* will be effected by the united rays of sound from different parts of the room, so that a whisper at *a*, will become audible at *b*, when it would not be heard in any other part of the room. Were the sides of the room lined with a polished metal, the rays of light or heat would be concentrated in the same manner.

The reason of this will be understood, when we consider, that an ear, placed at *c* will receive only one ray of the sound proceeding from *a*, while if placed at *b*, it will receive the rays from all parts of the room. Such a room, whether constructed by design or accident, would be a *whispering gallery*.

On a smooth surface, the rays, or pulses of sound, will pass with less impediment than on a rough one. For this reason, persons can talk to each other on the opposite sides of a river, when they could not be understood to the same distance over the land. The report of a cannon, at sea, when the water is smooth, may be heard at a great distance, but if the sea is rough, even without wind, the sound will be broken, and will reach only half as far.

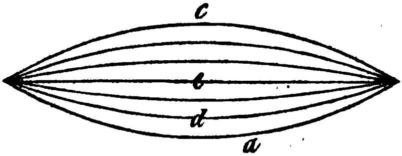
The *strings* of *musical instruments* are elastic cords, which being fixed at each end, produce sounds, by vibrating in the middle.

Explain fig. 114, and give the reason. Suppose a sound to be produced in one of the foci of an ellipse, where then might it be distinctly heard? Explain fig. 115, and give the reason. Why is it that persons can converse on the opposite sides of a river, when they could not hear each other at the same distance over the land? How do the strings of musical instruments produce sounds?

The string of a *violin* or *piano*, when pulled to one side by its middle, and let go, vibrates backwards and forwards, like a pendulum, and striking rapidly against the air, produces tones, which are grave, or acute, according to its tension, size, or length.

The manner in which such a string vibrates, is shown by fig. 116.

Fig. 116.



If pulled from *e* to *a*, it will not stop again at *e*, but in passing from *a* to *e*, it will gain a momentum, which will carry it to *c*, and in returning, its momentum will again carry it to *d*, and so on, backwards and forwards, like a pendulum, until its tension, and the resistance of the air, will finally bring it to rest.

The grave, or sharp tones of the same string, depend on its different degrees of tension; hence, if a string be struck, and while vibrating, its tension be increased, its tone will be changed from a lower to a higher pitch.

Strings of the same length are made to vibrate slow, or quick, and consequently to produce a variety of sounds, by making some larger than others, and giving them different degrees of tension. The *violin* and *bass viol* are familiar examples of this. The low, or bass strings, are covered with metallic wire, in order to make their magnitude and weight, prevent their vibrations from being too rapid, and thus they are made to give deep or grave tones. The other strings are diminished in thickness, and increased in tension, so as to make them produce a greater number of vibrations in a given time, and thus their tones become sharp or acute, in proportion.

Under certain circumstances, a long string will divide itself into halves, thirds, or quarters, without depressing any part of it, and thus give several harmonious tones at the same time. The fairy tones of the Æolian harp are produced in this manner. This instrument consists of a simple box of wood, with four or five strings, two or three feet long, fastened at

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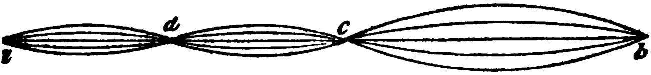
Explain fig. 116. On what do the grave or acute tones of the same string depend? Why are the bass strings of instruments covered with metallic wire? Why is there a variety of tones in the Æolian harp, since all the strings are tuned in unison?

each end. These are tuned in unison, so that when made to vibrate with force, they produce the same tones. But when suspended in a gentle breeze, each string, according to the manner or force in which it receives the blast, either sounds as a whole, or is divided into several parts, as above described. "The result of which," says Dr. Arnot, "is the production of the most pleasing combination, and succession of sounds, that the ear ever listened to, or fancy perhaps conceived. After a pause, this fairy harp is often heard beginning with a low, and solemn note, like the bass of distant music in the sky; the sound then swells as if approaching, and other tones break forth, mingling with the first, and with each other."

The manner in which a string vibrates in parts, will be understood by fig. 117.

Fig. 117.



Suppose the whole length of the string to be from *a* to *b*, and that it is fixed at these two points. The portion from *b* to *c*, vibrates as though it was fixed at *c*, and its tone differs from those of the other parts of the string. The same happens from *c* to *d*, and from *d* to *a*. While a string is thus vibrating, if a small piece of paper be laid on the part *c*, or *d*, it will remain, but if placed on any other part of the string, it will be shaken off.

Wind.

Wind is nothing more than air in motion. The use of a fan, in warm weather, only serves to move the air, and thus to make a little breeze about the person using it.

As a natural phenomenon, that motion of the air which we call wind, is produced in consequence of there being a greater degree of heat in one place than in another. The air thus heated, rises upward, while that which surrounds this, moves forward to restore the equilibrium.

The truth of this is illustrated by the fact, that during the burning of a house in a calm night, the motion of the air towards the place, where it is thus rarefied, makes the wind blow from every point towards the flame.

Explain fig. 117, showing the manner in which strings vibrate in parts. What is wind? As a natural phenomenon how is wind produced, or, what is the cause of wind? How is this illustrated?

In islands situated in hot climates, this principle is charmingly illustrated. The land, during the day time, being under the rays of a tropical sun, becomes heated in a greater degree than the surrounding ocean, and consequently, there rises from the land a stream of warm air, during the day, while the cooler air from the surface of the water, moving forward to supply this partial vacancy, produces a cool breeze setting inland on all sides of the island. This constitutes the *sea breeze*, which is so delightful to the inhabitants of those hot countries, and without which men could hardly exist in some of the most luxuriant islands between the tropics.

During the night the motion of the air is reversed, because the earth being heated superficially, soon cools when the sun is absent, while the water being warmed several feet below its surface retains its heat longer.

Consequently towards morning, the earth becomes colder than the water, and the air sinking down upon it, seeks an equilibrium by flowing outwards, like rays from a centre, and thus the *land breeze* is produced.

The wind then continues to blow from the land, until the equilibrium is restored, or until the morning sun makes the land of the same temperature as the water, when for a time there will be a dead calm. Then again the land becoming warmer than the water, the sea breeze returns as before, and thus the inhabitants of those sultry climates are constantly refreshed during the summer season, with alternate land and sea breezes.

At the equator, which is a part of the earth continually under the heat of a burning sun, the air is expanded and ascends upwards so as to produce currents from the north and south, which move forward to supply the place of the heated air as it rises. These two currents, coming from latitudes where the daily motion of the earth is less than at the equator, do not obtain its full rate of motion, and therefore when they approach the equator, do not move so fast eastward as that portion of the earth, by the difference between the equator's velocity, and that of the latitudes from which they come. This wind therefore falls behind the earth in her diurnal motion, and consequently has a relative motion towards the

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In the islands of hot climates, why does the wind blow inland during the day, and off the land during the night? What are these breezes called? What is said of the ascent of heated air at the equator? What is the consequence on the air towards the north and south?

west. This constant breeze towards the west is called the *trade wind*, because a large portion of the commerce of nations comes within its influence.

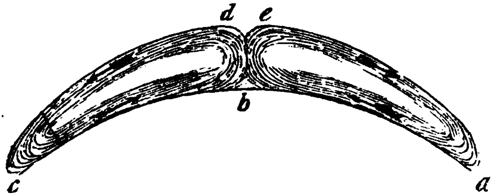
While the air in the lower regions of the atmosphere is thus constantly flowing from the north and south towards the equator, and forming the trade winds between the tropics, the heated air from these regions as perpetually rises and forms a counter current through the higher regions towards the north and south from the tropics, thus restoring the equilibrium.

This counter motion of the air in the upper and lower regions is illustrated by a very simple experiment. Open a door a few inches, leading into a heated room, and hold a lighted candle at the top of the passage; the current of air as indicated by the direction of the flame, will be *out* of the room. Then set the candle on the floor, and it will show that the current is there *into* the room. Thus, while the heated air rises and passes out of the room, that which is colder flows in, along the floor, to take its place.

This explains the reason why our feet are apt to suffer with the cold, in a room moderately heated, while the other parts of the body are comfortable. It also explains why those who sit in the gallery of a church are sufficiently warm, while those who sit below may be shivering with the cold.

From such facts, showing the tendency of heated air to ascend, while that which is colder moves forward to supply its place, it is easy to account for the reason why the wind blows perpetually from the north and south towards the tropics; for, the air being heated, as stated above, it ascends, and then flows north and south towards the poles, until, growing cold, it sinks down, and again flows towards the equator.

Fig. 118.



Perhaps these opposite motions of the two currents will be better understood by the sketch, figure 118.

How are the trade winds formed? While the air in the lower regions flows from the north and south towards the equator, in what direction does it flow in higher regions? How is this counter current in lower and upper regions illustrated by a simple experiment?

Suppose *a b c* to represent a portion of the earth's surface, *a* being towards the north pole, *c* towards the south pole, and *b* the equator. The currents of air are supposed to pass in the direction of the arrows. The wind, therefore, from *a* to *b* would blow, on the surface of the earth, from north to south, while from *e* to *a*, the upper current would pass from south to north, until it came to *a*, when it would change its direction towards the south. The currents in the southern hemisphere being governed by the same laws, would assume similar directions.

OPTICS.

Optics is that science which treats of vision, and the properties and phenomena of light.

The term *optics* is derived from a Greek word, which signifies *seeing*.

This science involves some of the most elegant and important branches of natural philosophy. It presents us with experiments which are attractive by their beauty, and which astonish us by their novelty; and, at the same time, it investigates the principles of some of the most useful among the articles of common life.

There are two opinions concerning the nature of light. Some maintain that it is composed of material particles, which are constantly thrown off from the luminous body; while others suppose that it is a fluid diffused through all nature, and that the luminous, or burning body, occasions waves or undulations in this fluid, by which the light is propagated in the same manner as sound is conveyed through the air. The most probable opinion, however, is, that light is composed of exceedingly minute particles of matter. But whatever may be the nature or cause of light, it has certain general properties or effects which we can investigate. Thus, by experiments, we can determine the laws by which it is governed in its passage through different transparent substances, and also those by which it is governed when it strikes a substance through which it cannot pass. We can likewise test its nature to a certain degree, by decomposing or dividing it into its elementary parts, as the chemist decomposes any substance he wishes to analyze.

What common fact does this experiment illustrate? Define Optics What is said of the elegance and importance of this science? What are the two opinions concerning the nature of light? What is the most probable opinion?

To understand the science of optics, it is necessary to define several terms, which, although some of them may be in common use, have a technical meaning, when applied to this science.

Light is that principle, or substance, which enables us to see any body from which it proceeds. If a luminous substance, as a burning candle, be carried into a dark room, the objects in the room become visible, because they reflect the light of the candle to our eyes. (*For the Chemical effects of Light, see Chemistry.*)

Luminous bodies are such as emit light from their own substance. The sun, fire, and phosphorus, are luminous bodies. The moon, and the other planets are not luminous, since they borrow their light from the sun.

Transparent bodies are such as permit the rays of light to pass freely through them. Air and some of the gases are perfectly transparent, since they transmit light without being visible themselves. Glass and water are also considered transparent, but they are not perfectly so, since they are themselves visible, and therefore do not suffer the light to pass through them without interruption.

Translucent bodies are such as permit the light to pass, but not in sufficient quantity to render objects distinct, when seen through them.

Opaque is the reverse of transparent. Any body which permits none of the rays of light to pass through it, is opaque.

Illuminated, enlightened. Any thing is illuminated when the light shines upon it, so as to make it visible. Every object exposed to the sun is illuminated. A lamp illuminates a room, and every thing in it.

A *Ray* is a single line of light, as it comes from a luminous body.

A *Beam* of light is a body of parallel rays.

A *Pencil* of light is a body of diverging or converging rays.

Divergent rays, are such as come from a point, and continually separate wider apart, as they proceed.

What is light? What is a luminous body? What is a transparent body? Are glass and water perfectly transparent? How is it proved that air is perfectly transparent? What are translucent bodies? What are opaque bodies? What is meant by illuminated? What is a ray of light? What is a beam? What a pencil? What are divergent rays?

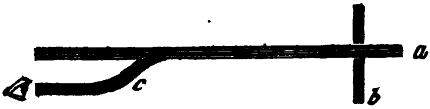
Convergent rays, are those which approach each other, so as to meet at a common point.

Luminous bodies emit rays, or pencils of light, in every direction, so that the space through which they are visable is filled with them at every possible point.

Thus, the sun illuminates every point of space, within the whole solar system. A light, as that of a light house, which can be seen from the distance of ten miles in one direction, fills every point in a circuit of ten miles from it, with light. Were this not the case, the light from it could not be seen from every point within that circumference.

The rays of light move forward in straight lines from the luminous body, and are never turned out of their course except by some obstacle.

Fig. 119.



Let *a*, fig. 119, be a beam of light from the sun passing through a small orifice in the window shutter *b*. The sun cannot be seen through the crooked tube *c*, because the beam passing in a straight line, strikes the side of the tube, and therefore does not pass through it.

All the illuminated bodies, whether natural or artificial, throw off light in every direction of the same color as themselves, though the light with which they are illuminated is white or without color.

This fact is obvious to all who are endowed with sight. Thus, the light proceeding from grass is green, while that proceeding from a rose is red, and so of every other color.

We shall be convinced, in another place, that the white light with which things are illuminated is really composed of several colors, and that bodies reflect only the rays of their own colors, while they absorb all the other rays.

Light moves with the amazing rapidity of about 95 millions of miles in 8½ minutes, since it is proved by certain astronomical observations, that the light of the sun comes to the

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What are convergent rays? In what direction do luminous bodies emit light? How is it proved that a luminous body fills every point within a certain distance with light? Why cannot a beam of light be seen through a bent tube? What is the color of the light which different bodies throw off? If grass throws off green light, what becomes of the other rays?

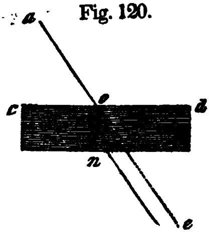
earth in that time. This velocity is so great, that to any distance at which an artificial light can be seen, it seems to be transmitted instantaneously.

If a ton of gunpowder were exploded on the top of a mountain, where its light could be seen a hundred miles, no perceptible difference would be observed in the time of its appearance on the spot, and at the distance of a hundred miles.

Refraction of Light.

Although a ray of light will always pass in a straight line, when not interrupted, yet when it passes obliquely from one transparent body into another, of a different density, it leaves its linear direction, and is bent, or *refracted*, more or less, out of its former course. This change in the direction of light, seems to arise from a certain power, or quality, which transparent bodies possess in different degrees; for some substances bend the rays of light much more obliquely than others.

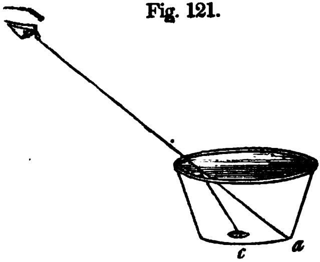
Fig. 120.



The manner in which the rays of light are refracted, may be readily understood by fig. 120.

Let *a* be a ray of the sun's light, proceeding obliquely towards the surface of the water *c*, *d*, and let *e* be the point which it would strike, if moving only through the air. Now, instead of passing through the water in the line *a*, *e*, it will be bent or refracted, on entering the water, from *o* to *n*, and having passed through the fluid it is again refracted in a contrary direction on passing out of the water, and then proceeds onward in a straight line as before.

Fig. 121.



The refraction of water is beautifully proved by the following simple experiment. Place an empty cup, fig. 121, with a shilling on the bottom, in such a position, that the side

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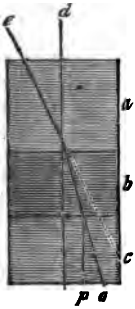
What is the rate of velocity with which light moves? Can we perceive any difference in the time which it takes an artificial light to pass to us from a great or small distance? What is meant by the refraction of light? Do all transparent bodies refract light equally?

of the cup will just hide the piece of money from the eye. Then let another person fill the cup with water, keeping the eye in the same position as before. As the water is poured in, the shilling will become visible, appearing to rise with the water. The effect of the water is to bend the ray of light coming from the shilling, so as to make it meet the eye below the point where it otherwise would. Thus the eye could not see the shilling in the direction of *c*, since the line of vision is towards *a*, and *c* is hidden by the side of the cup. But the refraction of the water bends the ray downwards, producing the same effect as though the object had been raised upwards, and hence it becomes visible.

The transparent body through which the light passes is called the *medium*, and it is found in all cases, "*that where a ray of light passes obliquely from one medium into another of a different density, it is refracted, or turned out of its former course.*" This is illustrated in the above examples, the water being a more dense medium than the air. The refraction takes place at the surface of the medium, and the ray is refracted in its passage *out* of the refracting substance as well as *into* it.

If the ray, after having passed through the water, then strikes upon a still more dense medium, as a pane of glass, it will again be refracted. It is understood, that in all cases the ray must fall upon the refracting medium obliquely in order to be refracted, for if it proceeds from one medium to another perpendicularly to their surfaces, it will pass straight through them all, and no refraction will take place.

Fig. 122.

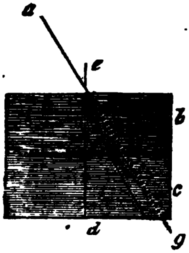


Thus, in fig. 122, let *a* represent air, *b* water, and *c* a piece of glass. The ray *d* striking each medium in a perpendicular direction, passes through them all in a straight line. The oblique ray passes through the air in the direction of *c*, but meeting the water, is refracted in the direction of *o;* then falling upon the glass, it is again refracted in the direction of *p*, nearly parallel with the perpendicular line *d*.

Explain fig. 120. and show how the ray is refracted in passing into and out of the water. Explain fig. 121, and state the reason why the shilling seems to be raised up by pouring in the water. What is a medium? In what direction must a ray of light pass towards the medium to be refracted? Will a ray falling perpendicularly on a medium be refracted? Explain fig. 122, and show how the ray *e* is refracted.

In all cases where the ray passes out of a rarer into a denser medium, it is refracted towards a perpendicular line, raised from the surface of the denser medium, and so, when it passes out of a denser, into a rarer medium, it is refracted from the same perpendicular.

Fig. 123.

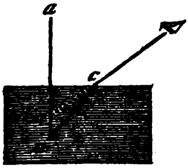


Let the medium *b*, fig. 123, be glass, and the medium *c*, water. The ray *a*, as it falls upon the medium *b*, is refracted towards the perpendicular line *e*, *d;* but when it enters the water, whose refractive power is less than that of glass, it is not bent so near the perpendicular as before, and hence it is refracted *from*, instead of towards the perpendicular line, and approaches the original direction of the ray *a*, *g*, when passing through the air.

The cause of refraction appears to be the power of attraction, which the denser medium exerts on the passing ray and in all cases the attracting force acts in the direction of a perpendicular to the refracting surface.

The refraction of the rays of light, as they fall upon the surface of the water, is the reason why a straight rod, with one end in the water and the other end rising above it, appears to be broken, or bent, and also to be shortened.

Fig. 124.



Suppose the rod *a*, fig. 124, to be set with one half of its length below the surface of the water, and the other half above it. The eye being placed in an oblique direction, will see the lower end apparently at the point *o*, while the real termination of the rod would be at *n*: the refraction will therefore make the rod appear shorter by the distance from *o* to *n*, or one fourth shorter than the part below the water really is. The reason why the rod appears distorted, or broken, is, that we judge of the direction of the part which is under the water, by that which is above it, and the refraction of the rays coming from below the surface of the water, give them a different direction, when compared with those coming from that part of the rod which is above it. Hence, when

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When the ray passes out of a rarer into a denser medium, in what direction is it refracted? When it passes out of a denser into a rarer medium, in what direction is the refraction? Explain this by fig. 123. What is the cause of refraction? What is the reason that a rod, with one end in the water, appears distorted and shorter than it really is?

the whole rod is below the water, no such distorted appearance is observed, because then all the rays are refracted equally.

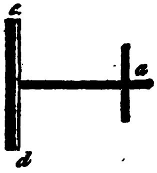
For the reason just explained, persons are often deceived in respect to the depth of water, the refraction making it appear much more shallow than it really is; and there is no doubt but the most serious accidents have often happened to those who have gone into the water under such deception; for a pond which is really six feet deep, will appear to the eye only a little more than four feet deep.

Reflection of Light.

If a boy throws his ball against the side of a house swiftly, and in a perpendicular direction, it will bound back nearly in the line in which it was thrown, and he will be able to catch it with his hands; but if the ball be thrown obliquely to the right, or left, it will bound away from the side of the house in the same relative direction in which it was thrown.

The reflection of light, so far as regards the line of approach, and the line of leaving a reflecting surface, is governed by the same law.

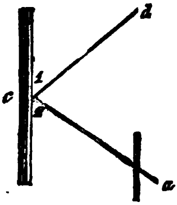
Fig. 125.



Thus, if a sun beam, fig. 125, passing through a small aperture in the window shutter *a*, be permitted to fall upon the plane mirror, or looking glass, *c*, *d*, at right angles, it will be reflected back at right angles with the mirror, and therefore will pass back again in exactly the same direction in which it approached.

But if the ray strikes the mirror in an oblique direction, it will also be thrown off in an oblique direction opposite to that in which it was thrown.

Fig. 126.



Let a ray pass towards a mirror in the line *a*, *c*, fig. 126, it will be reflected off in the direction of *c*, *d*, making the angles 1 and 2 exactly equal.

The ray *a*, *c*, is called the *incident* ray, and the ray *c*, *d*, the *reflected* ray; and it is found in all cases, that whatever angle the ray of incidence makes with the reflect-

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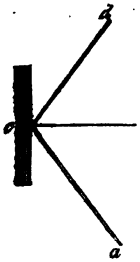
Why does the water in a pond appear less deep than it really is? Suppose a sun beam fall upon a plane mirror at right angles with its surface, in what direction will it be reflected? Suppose the ray falls obliquely on its surface, in what direction will it then be reflected? What is an incident ray of light? What is a reflected ray of light?

Fig. 127.



ing surface, or with a perpendicular line drawn from the reflecting surface, exactly the same angle is made by the reflected ray.

From these facts, arise the general law in optics, that the *angle of reflection is equal to the angle of incidence.*

The ray *a*, *c*, fig. 127, is the ray of incidence, and that from *c* to *d*, is the ray of reflection. The angles which *a*, *c*, make with the perpendicular line, and with the plane of the mirror, is exactly equal to those made by *c*, *d*, with the same perpendicular, and the same plane surface.

Mirrors.

Mirrors are of three kinds, namely, *plane*, *convex*, and *concave*. They are made of polished metal, or of glass covered on the back with an amalgam of tin and quicksilver.

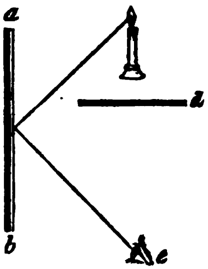
The common *looking glass* is a plane mirror, and consists of a plate of ground glass so highly polished as to permit the rays of light to pass through it with little interruption. On the back of this plate is placed the reflecting surface, which consists of a mixture of tin and mercury. The glass plate, therefore, only answers the purpose of sustaining the metallic surface in its place,—of admitting the rays of light to, and from it, and of preventing its surface from tarnishing, by excluding the air. Could the metallic surface, however, be retained in its place, and not exposed to the air without the glass plate, these mirrors would be much more perfect than they are, since, in practice, glass cannot be made so perfect as to transmit all the rays of light which fall on its surface.

When applied to the plane mirror, the angles of incidence and of reflection are equal, as already stated, and it therefore follows, that when the rays of light fall upon it obliquely in one direction, they are thrown off under the same angle in the opposite direction.

This is the reason why the images of objects can be seen when the objects themselves are not visible.

What general law in optics results from observations on the incident and reflected rays? How many kinds of mirrors are there? What kind of mirror is the common looking glass? Of what use is the glass plate in the construction of this mirror?

Fig. 128.



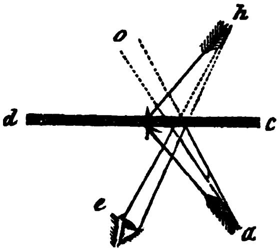
Suppose the mirror *a b*, fig. 128, to be placed on the side of a room, and a lamp to be set in another room, but so situated, as that its light would shine upon the glass. The lamp itself could not be seen by the eye placed at *e*, because the partition *d* is between them; but its image would be visible at *e*, because the angle of the incident ray, coming from the light, and that of the reflected ray which reaches the eye, are equal.

An image from a plane mirror appears to be just as far behind the mirror, as the object is before it, so that when a person approaches this mirror, his image seems to come forward to meet him; and when he withdraws from it, his image appears to be moving backward at the same rate. For the same reason the different parts of the same object will appear to extend as far behind the mirror, as they are before it.

If, for instance, one end of a rod two feet long be made to touch the surface of such a mirror, this end of the rod, and its image, will seem nearly to touch each other, there being only the thickness of the glass between them; while the other end of the rod, and the other end of its image, will appear to be equally distant from the point of contact.

The reason of this is explained on the principle, that the angle of incidence and that of reflection is equal.

Fig. 129.



Suppose the arrow *a*, to be the object reflected by the mirror *d c* fig. 129; the incident rays *a*, flowing from the end of the arrow, being thrown back by reflection, will meet the eye in the same state of divergence that they would do, if they proceeded to the same distance behind the mirror, that the eye is before it, as at *o*. Therefore, by the same

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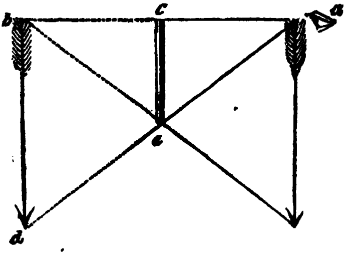
Explain fig. 128, and show how the image of an object can be seen in a plane mirror, when the real object is invisible. The image of an object appears just as far behind a plane mirror, as the object is before it; explain fig. 129, and show why this is the case.

law, the reflected rays, where they meet the eye at *e*, appear to diverge from a point *h*, just as far behind the mirror, as *a* is before it, and consequently the end of the arrow most remote from the glass, will appear to be at *h*, or the point where the approaching rays would meet, were they continued onward behind the glass. The rays flowing from every other part of the arrow follow the same law; and thus every part of the image seems to be at the same distance behind the mirror, that the object really is before it.

In a plane mirror, a person may see his whole image, when the mirror is only half as long as himself; let him stand at any distance from it whatever.

This is also explained by the law, that the angles of incidence and reflection are equal. If the mirror be elevated, so that the ray of light from the eye falls perpendicularly upon the mirror, this ray will be thrown back by reflection in the same direction, so that the incident and reflected ray by which the image of the eyes and face are formed, will be nearly parallel, while the ray flowing from his feet will fall on the mirror obliquely, and will be reflected as obliquely in the contrary direction, and so of all the other rays by which the image of the different parts of the person is formed.

Fig. 130.



Thus suppose the mirror *c e*, fig. 130, to be just half as long as the arrow placed before it, and suppose the eye to be placed at *a*. Then the ray *a e*, proceeding from the eye at *a*, and falling perpendicularly on the glass at *c*, will be reflected back to the eye in the same line, and this part of the image will appear at *b*, in the same line, and at the same distance behind the glass that the arrow is before it. But the ray flowing from the lower extremity of the arrow, will fall on the mirror obliquely, as at *e*, and will be reflected under the same angle to the eye, and therefore the extremity of the

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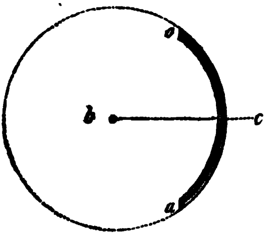
What must be the comparative length of a plane mirror, in which a person may see his whole image? In what part of the image, fig. 130, are the incidental and reflected rays nearly parallel? Why does the image of the lower part of the arrow appear at *d*?

image, appearing in the direction of the reflected ray, will be seen at *d*. The rays flowing from the other parts of the arrow, will observe the same law, and thus the whole image is seen distinctly, and in the same position as the object.

To render this still more obvious, suppose the mirror to be removed, and another arrow to be placed in the position where its image appears, behind the mirror, of the same length as the one before it. Then the eye, being in the same position as represented in the figure, would see the different parts of the real arrow in the same direction that it before saw the image. Thus the ray flowing from the upper extremity of the arrow, would meet the eye in the direction of *b c*, while the ray coming from the lower extremity, would fall on it in the direction of *e d*.

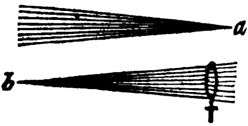
Fig. 131.



Convex Mirror. A convex mirror is a part of a sphere, or globe reflecting from the outside.

Suppose fig. 131 to be a sphere, then the part from *a* to *o*, would be a section of the sphere. Any part of a hollow ball of glass, with an amalgam of tin and quicksilver spread on the inside, or any part of a metallic globe polished on the outside, would form a convex mirror.

Fig. 132.



The *axis* of a convex mirror, is a line as *c b*, passing through its centre.

Rays of light are said to *diverge*, when they proceed from the same point, and constantly recede from each other, as from the point *a*, fig. 132. Rays of light are said to *converge*, when they approach each other in such a direction as finally to meet at a point, as at *b*, fig. 132.

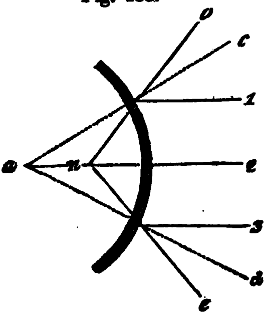
The image formed by a plane mirror, as we have already seen, is of the same size as the object, but the image reflected from the convex mirror is always smaller than the object.

Suppose the mirror, fig. 130, to be removed, and an arrow of the same length to be placed where the image appeared, would the direction of the rays from the arrow be the same that they were from the image? What is a convex mirror? What is the axis of a convex mirror? What are diverging rays? What are converging rays?

The law which governs the passage of light with respect to the angles of incidence and reflection, to and from the convex mirror, is the same as already stated, for the plane mirror

From the surface of a plane mirror, parallel rays are reflected parallel; but the convex mirror causes parallel rays falling on its surface to *diverge*, by reflection.

Fig. 133.



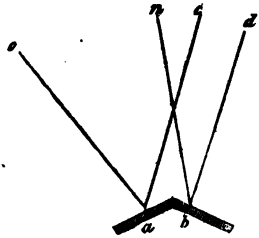
To make this understood, let 1, 2, 3, fig. 133, be parallel rays, falling on the surface of the convex reflector, of which *a* would be the centre, where the reflector a whole sphere. The ray 2 is perpendicular to the surface of the mirror, for when continued in the same direction, it strikes the axis, or centre of the circle *a*. The two rays 1 and 3, being parallel to this, all three would fall on a plane mirror, in a perpendicular direction, and consequently would be reflected in the lines of their incidence. But the obliquity of the convex surface it is obvious will render the direction of the rays 1 and 3, oblique to that surface, for the same reason that 2 is perpendicular to that part of the circle on which it falls. Rays falling on any part of this mirror, in a direction, which, if continued through the circumference, would strike the centre, are perpendicular to the side where they fall. Thus, the dotted lines *c a*, and *d a*, are perpendicular to the surface, as well as 2.

Now the reflection of the ray 2, will be back in the line of its incidence, but the rays 1 and 3, falling obliquely, are reflected under the same angles at which they fall, and therefore their lines of reflection will be as far without the perpendicular lines *c a*, and *d a*, as the lines of their incident rays, 1, and 3, are within them, and consequently they will diverge in the direction of *e* and *o;* and since we always see the image in the direction of the reflected ray, an object placed at 1, would appear behind the surface of the mirror at *n*, or in the direction of the line *o n*.

What law governs the passage of light from and to the convex mirror? Are parallel rays falling on a convex mirror, reflected parallel? Explain fig. 133.

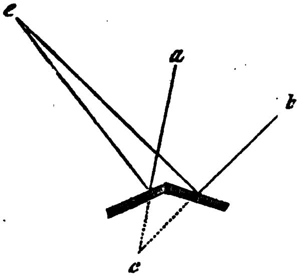
Perhaps the subject of the convex mirror will be better understood by considering its surface to be formed of a number of plane surfaces, indefinitely small. In this case, each point from which a ray is reflected, would act in the same manner as a plane mirror, and the whole, in the manner of a number of minute mirrors inclined from each other.

Fig. 134.



Suppose *a* and *b*, fig. 134, to be the points on a convex mirror from which the two parallel rays, *c* and *d*, are reflected. Now, from the surface of a plane mirror, the reflected rays would be parallel, whenever the incident ones are so, because each will fall upon the surface under the same angles. But it is obvious in the present case, that these rays fall upon the surfaces *a*, and *b*, under different angles, as respects the surfaces, *c*, approaching in a more oblique direction than *d*; consequently *c* is reflected more obliquely than *d*, and the two reflected rays, instead of being parallel, as before, diverge in the direction of *n* and *o*.

Fig. 135.



Again, the two converging rays *a* and *b*, fig. 135, without the interposition of the reflecting surfaces, would meet at *c*, but because the angles of reflection are equal to those of incidence, and because the surfaces of reflection are inclined to each other, these rays are reflected less convergent, and instead of meeting at the same distance before the mirror, that *c* is behind it, are sent off in the direction of *e*, at which point they meet.

"*Thus parallel rays falling on a convex mirror, are rendered diverging by reflection; converging rays are made less convergent, or parallel, and diverging rays more divergent.*

How is the action of the convex mirror illustrated by a number of plane mirrors? Explain fig. 135. What effect does the convex mirror have upon parallel rays by reflection? What is its effect on converging rays? What is its effect on diverging rays?

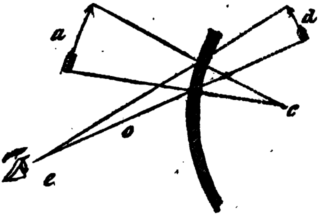
The effect of the convex mirror, therefore, is to disperse the rays of light in all directions; and it is proper here to remind the pupil, that although the rays of light are represented on paper by single lines, there are in fact probably millions of rays, proceeding from every point of all visible bodies. Only a comparatively small number of these rays, it is true, can enter the eye, for it is only by those which proceed in straight lines from the different parts of the object, and enter the pupil, that the sense of vision is excited.

Now, to conceive how exceedingly small must be the proportion of light thrown off, from any visible object which enters the eye, we must consider that the same object reflects rays in every other direction, as well as in that in which it is seen. Thus, the gilded ball on the steeple of a church may be seen by millions of persons at the same time, who stand upon the ground; and were millions more raised above these, it would be visible to all.

When, therefore, it is said, that the convex mirror disperses the rays of light which fall upon it from any object, and when the direction of these reflected rays are shown only by single lines, it must be remembered, that each line represents pencils of rays, and that the light not only flows from the parts of the object thus designated, but from all the other parts. Were this not the case, the object would be visible only at certain points.

The images of objects reflected from the convex mirror appear curved, because their different parts are not equally distant from its surface.

Fig. 136.



If the object *a*, be placed obliquely before the convex mirror, fig. 136, then the converging rays from its two extremities falling obliquely on its surface, would, were they prolonged through the mirror, meet at the point *c*, behind it. But instead of being thus continued, they are thrown back by the mirror, in less conver-

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Do the rays of light proceed only from the extremities of objects, as represented in figures, or from all their parts? Do all the rays of light proceeding from an object enter the eye, or only a few of them? What would be the consequence, if the rays of light proceeded only from the parts of an object shown in diagrams? Why do the images of objects reflected from convex mirrors appear curved?

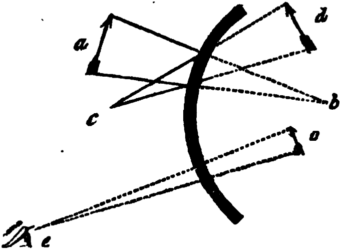
gent lines, which meet the eye at *c*, it being, as we have seen, one of the properties of this mirror, to reflect converging rays less convergent than before.

The image being always seen in the direction from which the rays approach the eye, it appears behind the mirror at *d*. If the eye be kept in the same position, and the object *a*, be moved further from the mirror, its image will appear smaller, in a proportion inversely to the distance to which it is removed. Consequently, by the same law, the two ends of a straight object will appear smaller than its middle, because they are further from the reflecting surface of the mirror. Thus, the images of straight objects, held before a convex mirror, appear curved, and for the same reason, the features of the face appear out of proportion, the nose being too large, and the cheeks too small, or narrow.

The reason why the image appears less than the object is, that the convex surface of the mirror has the property, as stated above, of decreasing the convergency of the incidental rays by reflection.

Now, objects appear to us large or small, in proportion to the angle which the rays of light, proceeding from their extreme parts form, when they meet at the eye. For it is plain that the half of any object will appear under a less angle than the whole, and the quarter under a less angle still. Therefore the smaller an object is, the smaller will be the angle under which it will appear at a given distance. If then a mirror makes the angle under which an object is seen smaller, the object itself will seem smaller than it really is. Hence the image of an object, when reflected from the convex mirror, appears smaller than the object itself. This will be understood by fig. 137.

Fig. 137.



Suppose the rays flowing from the extremities of the object *a*, to be reflected back to *c*, under the same degrees of convergence at which they strike the mirror, then as in

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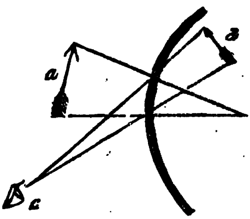
Why do the features of the face appear out of proportion, by this mirror? Why does an image reflected from a convex surface appear smaller than the object? Why does the half of an object appear to the eye smaller than the whole?

the plane mirror, the image *d*, would appear of the same size as the object *a;* for if the rays from *a* were prolonged behind the mirror, they would meet at *b*, but forming the same angle, by reflection, that they would do, if thus prolonged, the object seen from *b*, and its image from *c*, would appear of the same dimensions.

But instead of this, the rays from the arrow *a*, being rendered less convergent by reflection, are continued onward, and meet the eye under a more acute angle than at *c*, the angle under which they actually meet, being represented at *e*, consequently the image of the object is shortened in proportion to the acuteness of this angle, and the object appears diminished, as represented at *o*.

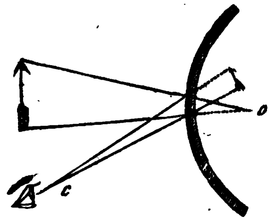
Fig. 138.



The image of an object, as already stated, appears less as the object is removed to a greater distance from the mirror.

To explain the reason of this, let us suppose that the arrow *a*, fig. 138, is diminished by reflection from the convex surface, so that its image appearing at *d*, with the eye at *c*, shall seem as much smaller in proportion to the object, as *d* is less than *a*. Now, keeping the eye at the same distance from the mirror, withdraw the object, so that it shall be equally distant with the eye, and the image will gradually diminish, as the arrow is removed.

Fig. 139.



The reason of this will be made plain by the next figure; for as the arrow is moved backwards, the angle at *c*, fig. 139, must be diminished, because the rays flowing from the extremities of the object fall a greater distance before they reach the surface of the mirror; and as the angles of the reflected rays bear a proportion to those of the

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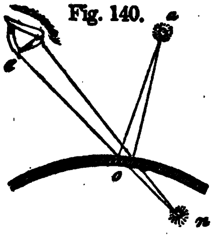
Suppose the angles *c* and *b*, fig. 137, are equal, will there be any difference between the size of the object and its image? How is the image affected, when the object is withdrawn from the surface of a convex mirror? Explain figures 138 and 139, and show the reason why the images are diminished when the objects are removed from the convex mirror.

incident ones, so the angle of vision will become less in proportion as the object is withdrawn. The effect therefore of withdrawing the object, is first to lessen the distance between the converging rays, flowing from it, at the point where they strike the mirror, and as a consequence to diminish the angle under which the reflected rays convey its image to the eye.

In the plane mirror, as already shown, the image appears exactly as far behind the mirror as the object is before it, but the convex mirror shows the image just under the surface, or, when the object is removed to a distance, a little way behind it. To understand the reason of this difference, it must be remembered, that the plane mirror makes the image seem as far behind, as the object is before it, because the rays are reflected in the same relative position, at which they fall upon its surface. Thus, parallel rays are reflected parallel; divergent rays equally divergent, and convergent rays equally convergent. But the convex mirror, as also above shown, reflects convergent rays less convergent, and divergent rays more divergent, and it is from this property of the convex mirror that the image appears near its surface, and not as far behind it as the object is before it, as in the plane mirror.

Fig. 140.



Let us suppose that *a*, fig. 140, is a luminous point, from which a pencil of diverging rays fall upon a convex mirror. These rays, as already demonstrated, will be reflected more divergent, and consequently will meet the eye at *e*, in a wider state of dispersion than they fell upon the mirror at *o*. Now, as the image will appear at the point where the diverging rays would converge to a focus in a contrary direction, were they prolonged behind the mirror, so it cannot appear as far behind the reflecting surface as the object is before it, for the more widely the rays meeting at the eye are separated, the shorter will be the distance at which they will come to a point. The image will therefore appear at *n*, instead of appearing at an equal distance behind the mirror that the object *a* is before it.

What is said to be the first effect of withdrawing the object from a concave surface, and what the consequence on the angle of reflected rays? Explain the reason why the image appears near the surface of the convex mirror.

Concave Mirror. The shape of the *concave mirror*, is exactly like that of the convex mirror, the only difference between them being in respect to their reflecting surfaces. The reflection of the concave mirror takes place from its inside, or concave surface, while that of the convex mirror is from the outside, or convex surface. Thus the section of a metallic sphere, polished on both sides, is both a concave and convex mirror, as one or the other side is employed for reflection.

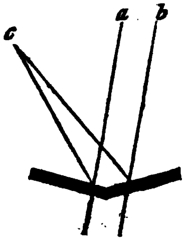
The effect and phenomena of this mirror will therefore be, in many respects, directly the contrary from those already detailed in reference to the convex mirror.

From the *plane* mirror the relation of the incident rays are not changed by reflection; from the *convex* mirror they are dispersed; but the *concave* mirror renders the rays reflected from it more convergent, and tends to concentrate them into a focus.

The surface of the concave mirror, like that of the convex, may be considered as a great number of minute plane mirrors, inclined to each other at certain angles, in proportion to its concavity.

The laws of incidence and reflection, are the same when applied to the concave mirror, as those already explained in reference to the other mirrors.

Fig. 141.



In reference to the concave mirror, let us, in the first place, examine the effect of two plane mirrors inclined to each other, as in fig. 141, on parallel rays of light. The incident rays, *a* and *b*, being parallel before they reach the reflectors, are thrown off at unequal angles in respect to each other, for *b* falls on the mirror more obliquely than *a*, and consequently is thrown off more obliquely in a contrary direction, therefore, the angles of reflection being equal to those of incidence, the two rays meet at *c*. Thus we see that the effect of two plane mirrors inclined to each other, is to make parallel rays converge and meet in a focus.

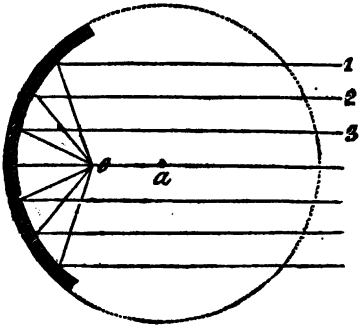
What is the shape of the concave mirror, and in what respect does it differ from the convex mirror? How may convex and concave mirrors be united in the same instrument? What is the difference of effect between the concave, convex, and plane mirrors, on the reflected rays? In what respect may the concave mirror be considered as a number of plane mirrors?

The same result would take place, whether the mirror was one continued circle, or an infinite number of small mirrors inclined to each other in the same relation as the different parts of the circle.

The effect of this mirror, as we have seen, being to render parallel rays convergent, the same principle will render diverging rays parallel, and converging rays still more convergent.

The *focus* of a concave mirror is the point where the rays are brought together by reflection. The *centre of concavity* in a concave mirror, is the centre of the sphere, of which the mirror is a part. In all concave mirrors, the focus of parallel rays, or rays falling directly from the sun, is at the distance of half the semi-diameter of the sphere, or globe, of which the reflector is a part.

Fig. 142.



Thus, the parallel rays 1, 2, 3, &c. fig. 142, all meet at the point *o*, which is half the distance between the centre *a* of the whole sphere, and the surface of the reflector, and therefore one quarter the diameter of the whole sphere, of which the mirror is a part.

In concave mirrors of all dimensions, the reflected rays follow the same law; that is, parallel rays meet and cross each other at the distance of one fourth the diameter of the sphere of which they are sections. This point is called the *principal* focus of the reflector.

But if the incident rays are divergent, the focus will be removed to a greater distance from the surface of the mirror, than when they are parallel, in proportion to their divergency.

This might be inferred from the general laws of incidence and reflection, but will be made obvious by fig. 143, where

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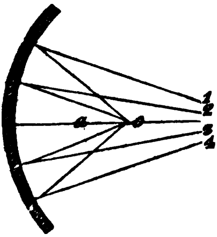
What is the focus of a concave mirror? At what distance from its surface is the focus of parallel rays in this mirror? What is the principal focus of a concave mirror?

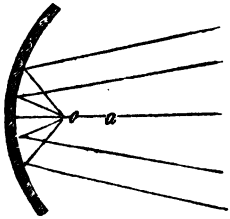
Fig. 143.



the diverging rays 1, 2, 3, 4, form a focus at the point *o*, whereas had they been parallel, their focus would have been at *a*. That is, the actual focus is at the centre of the sphere, instead of being half way between the centre and circumference, as is the case when the incident rays are parallel. The real focus therefore is beyond, or without the principal focus of the mirror.

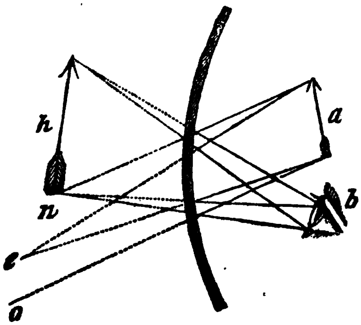
By the same law, converging rays will form a point within the principal focus of a mirror.

Fig. 144.



Thus, were the rays falling on the mirror, fig. 144, parallel, the focus would be at *a*; but in consequence of their previous convergency, they are brought together at a less distance than the principal focus and meet at *o*.

Fig. 145.



The images of objects reflected by a convex mirror we have seen, are smaller than the objects themselves. But the concave mirror, when the object is nearer to it than the principal focus, presents the image larger than the object, erect, and behind the mirror.

To explain this, let us suppose the object *a*, fig. 145, to be placed before the mirror, and nearer to it than the principal focus. Then the rays proceeding from the extremities of the object without interruption would continue to diverge in the lines *o* and

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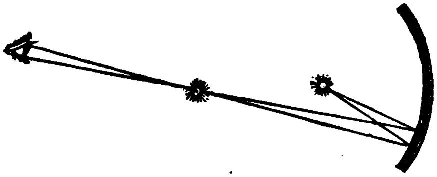
If the incident rays are divergent, where will be the focus? If the incident rays are convergent, where will be the focus? When will the image from a concave mirror be larger than the object, erect, and behind the mirror? Explain fig. 145, and show why the image is larger than the object.

a, as seen behind the mirror; but by reflection they are made to diverge less than before, and consequently to make the angle under which they meet more obtuse at the eye *b*, than it would be if they continued onward to *e*, where they would have met without reflection. The result, therefore, is to render the image *h*, upon the eye, as much larger than the object *a*, as the angle at the eye is more obtuse than the angle at *e*.

On the contrary, if the object is placed more remote from the mirror than the principal focus, and between the focus and the centre of the sphere of which the reflector is a part, then the image will appear inverted on the contrary side of the centre, and farther from the mirror than the object; thus, if a lamp be placed obliquely before a concave mirror, as in fig. 146, its image will be seen inverted in the air on the contrary side of a perpendicular line through the centre of the mirror.

Fig. 146.



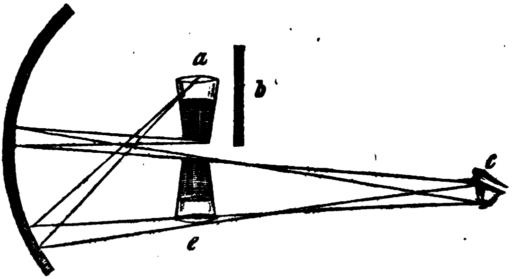
From the property of the concave mirror to form an inverted image of the object suspended in the air, many curious and surprising deceptions may be produced. Thus, when the mirror, the object, and the light, are placed so that they cannot be seen, (which may be done by placing a screen before the light, and permitting the reflected rays to pass through a small aperture in another screen,) the person mistakes the image of the object for its reality, and not understanding the deception, thinks he sees persons walking with their heads downwards and cups of water turned bottom upwards without spilling a drop. Again, he sees clusters of delicious fruit, and when invited to help himself, on reaching out his hand for that purpose, he finds that the object either suddenly vanishes from his sight, owing to his having moved his eye out of the proper range, or that it is intangible.

This kind of deception may be illustrated by any one who has a concave mirror only of three or four inches in diameter, in the following manner:

When will the image from the concave mirror be inverted and before the mirror? What property has the concave mirror by which singular deceptions may be produced? What are these deceptions?

Suppose the tumbler *a*, to be filled with water, and placed beyond the principal focus of the concave mirror, fig. 147, and so managed as to be hid from the eye *c*, by the screen *b*. The lamp by which the tumbler is illuminated must also be placed behind the screen, and near the tumbler. To a person placed at *c*, the tumbler with its contents will appear inverted at *e*, and suspended in the air. By carefully moving forward, and still keeping the eye in the same line with respect to the mirror, the person may pass his hand through the shadow of the tumbler; but without such conviction, any one unacquainted with such things, could hardly be made to believe that the image was not a reality.

Fig. 147.



By placing another screen between the mirror and the image, and permitting the converging rays to pass through an aperture in it, the mirror may be nearly covered from the eye, and thus the deception would be increased.

The image reflected from a concave mirror, moves in the same direction with the object, when the object is within the principal focus; but when the object is more remote than the principal focus, the image moves in a contrary direction from the object, because the rays then cross each other. If a man place himself directly before a large concave mirror, but farther from it than the centre of concavity, he will see an inverted image of himself in the air, between him and the mirror, but less than himself. And if he hold out his hand towards the mirror, the hand of his image will come out toward his hand, and he may imagine that he can shake hands

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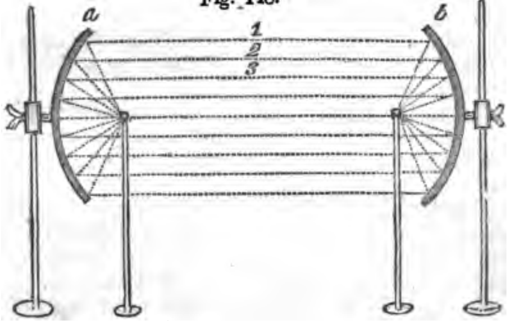
Describe the manner in which a tumbler with its contents may be made to seem inverted in the air. Why does the image move in a contrary direction from its object, when the object is beyond the principal focus?

with his image. But if he reach his hand further towards the mirror, the hand of the image will pass by his hand, and come between his hand and his body; and if he move his hand toward either side, the hand of the image will move in a contrary direction, so that if the object moves one way the image will move the other.

The concave mirror, having the property of converging the rays of light, is equally efficient in concentrating the rays of heat, either separately, or with the light. When, therefore, such a mirror is presented to the rays of the sun, it brings them to a focus, so as to produce degrees of heat in proportion to the extent and perfection of its reflecting surface. A metallic mirror of this kind, of only four or six inches in diameter, will fuse metals, set wood on fire, &c.

As the parallel rays of heat or light are brought to a focus at the distance of one quarter of the diameter of the sphere, of which the reflector is a section, so if a luminous or heated body be placed at this point, the rays from such body passing to the mirror will be reflected from all parts of its surface, in parallel lines; and the rays so reflected, by the same law, will be brought to a focus by another mirror standing opposite to this

Fig. 148.



Suppose a red hot ball to be placed in the principal focus of the mirror *a*, fig. 148, the rays of heat and light proceeding from it will be reflected in the parallel lines 1, 2, 3, &c. The reason of this is the same as that which causes parallel rays, when falling on the mirror, to be converged to a

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Will the concave mirror concentrate the rays of heat, as well as those of light? Suppose a luminous body be placed in the focus of a concave mirror, in what direction will its rays be reflected?

focus. The angles of incidence being equal to those of reflection, it makes no difference in this respect, whether the rays pass to or from the focus. In one case, parallel incident rays from the sun, are concentrated by reflection; and in the other, incident diverging rays, from the heated ball, are made parallel by reflection.

The rays therefore, flowing from the hot ball to the mirror *a*, are thrown into parallel lines by reflection, and these reflected rays, in respect to the mirror *b*, become the rays of incidence, which are again brought to a focus by reflection.

Thus the heat of the ball, by being placed in the focus of one mirror, is brought to a focus by the reflection of the other mirror.

Several striking experiments may be made with a pair of concave mirrors placed facing each other as in the figure. If a red hot ball be placed in the focus of *a*, and some gun powder in the focus of *b*, the mirrors being ten or twenty feet apart, according to their dimensions, the powder will flash by the heat of the ball, concentrated by the second mirror. To show that it is not the direct heat of the ball which sets fire to the powder, a paper screen may be placed between the mirrors until every thing is ready. The operator will then only have to remove the screen, in order to flash the powder.

To show that heat and light are separate principles, place a piece of phosphorus in the focus of *b*, and when the ball is so cool as not to be luminous, remove the screen, and the phosphorus will instantly inflame.

Refraction by Lenses.

A Lens is a transparent body, generally made of glass, and so shaped that the rays of light in passing through it are either collected together or dispersed. Lens is a Latin word, which comes from *lentile*, a small flat bean.

It has already been shown, that when the rays of light pass from a rarer to a denser medium, they are refracted, or bent out of their former course, except when they happen to fall perpendicularly on the surface of the medium.

The point where no refraction is produced on perpendicular rays, is called the *axis* of the lens which is a right line

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Explain fig. 148, and show why the rays from the focus of *a* are concentrated in the focus *b*. What curious experiments may be made by two concave mirrors placed opposite to each other? How may it be shown that heat and light are distinct principles? What is a lens?

passing through its centre, and perpendicular to both its surfaces.

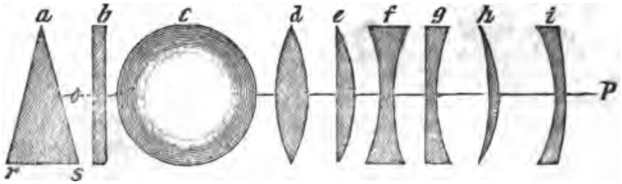
In every beam of light, the middle ray is called its *axis.*

Rays of light are said to fall *directly* upon a lens, when their axes coincide with the axes of the lens; otherwise they are said to fall *obliquely.*

The point at which the rays of the sun are collected, by passing through a lens, is called the *principal focus* of that lens.

Lenses are of various kinds, and have received certain names, depending on their shapes. The different kinds are shown at fig. 149.

Fig. 149.



A *prism,* seen at *a,* has two plane surfaces, *a r,* and *a s,* inclined to each other.

A *plane glass,* shown at *b,* has two plane surfaces, parallel to each other.

A *spherical lens, c,* is a ball of glass, and has every part of its surface at an equal distance from the centre.

A *double concave lens, d,* is bounded by two *convex* surfaces opposite to each other.

A *plano-concave lens, e,* is bounded by a convex surface on one side, and a plane on the other.

A *double-concave lens, f,* is bounded by two concave spherical surfaces, opposite to each other.

A *plano-concave lens, g,* is bounded by a plane surface on one side and a concave one on the other.

A *meniscus, h,* is bounded by one concave and one convex spherical surface, which two surfaces meet at the edge of the lens.

A *concavo-convex* lens *i,* is bounded by a concave and convex surface, but which diverge from each other, if continued,

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What is the axis of a lens? In what part of a lens is no refraction produced? Where is the axis of a beam of light? When are rays of light said to fall directly upon a lens? How many kinds of lenses are mentioned? What is the name of each? How are each of these lenses bounded?

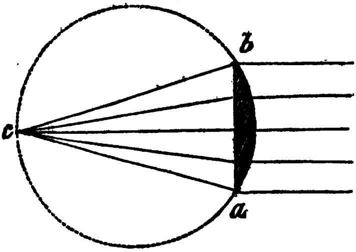
The effects of the prism on the rays of light will be shown in another place. The refraction of the *plane* glass, bends the parallel rays of light equally towards the perpendicular, as already shown. The *sphere* is not often employed as a lens, since it is inconvenient in use.

Convex lens. It has been shown in a former part of this article, that when a ray of light passes obliquely out of a rarer into a denser medium, it is refracted, or turned out of its former course.

Suppose, then, there is presented to the rays of light, a piece of glass, with its surface so shaped, that all the rays, except those which pass through its axis, are refracted towards the perpendicular, it is obvious that they would all finally meet the perpendicular ray, and there form a focus.

The focal distances of convex lenses, depend on their degrees of convexity. The focal distance of a single, or plano-convex lens, is the diameter of a sphere, of which it is a section.

Fig. 150.

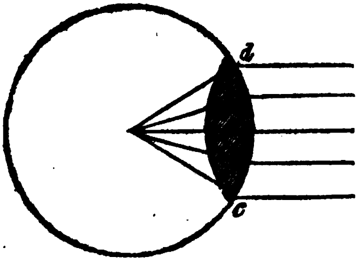


If the whole circle, fig. 150, be considered the circumference of a sphere of which the plano-convex lens, *b a*, is a section, then the focus of parallel rays, or the principal focus, will be at the opposite side of the sphere, or at *c*.

The focal distance of a double convex lens, is the radius, or half the diameter of the sphere of which it is a part. Hence the plano-convex lens, being one half the double convex lens, the latter has about twice the refractive power of the former; for the rays suffer the same degree of refraction in passing out of the one covex surface, that they do in passing into the other.

On what do the focal distances of convex lenses depend? What is the focal distance of any plano-convex lens? What is the focal distance of the double convex lens? What is the shape of the double convex lens?

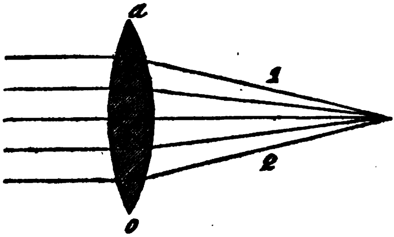
Fig. 151.



The shape of the double convex lens, *d c*, fig. 151, is that of two plano-convex lenses, placed with their plane surfaces in contact, and consequently the focal distance of this lens is nearly the centre of the sphere of which one of its surfaces is a part. If parallel rays fall on a convex lens, it is evident that the ray only, which penetrates the axis and passes towards the centre of the sphere, will proceed without refraction, as shown in the above figures. All the others will be refracted so as to meet the perpendicular ray at a greater or less distance, depending on the convexity of the lens.

If diverging rays fall on the surface of the same lens, they will by refraction, be rendered less divergent, parallel, or convergent, according to the degrees of their divergency, and the convexity of the surface of the lens.

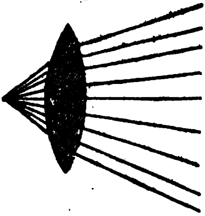
Fig. 152.



Thus, the diverging rays 1, 2, &c. fig. 152, are refracted by the lens *a o*, in a degree just sufficient to render them parallel, and therefore would pass off in right lines, indefinitely, or without ever forming a focus. It is obvious by the same law, that were the rays less divergent, or were the surface of the lens more convex, the rays in fig. 152 would become convergent, instead of parallel, because the same refractive power which would render divergent rays parallel, would make parallel rays convergent, and converging rays still more convergent.

How are divergent rays affected by passing through a convex lens? What is its effect on parallel rays? What is its effect on converging rays?

Fig. 153.



Thus, the pencils of converging rays, fig. 153, are rendered still more convergent by their passage through the lens, and are therefore brought to a focus nearer the lens, in proportion to their previous convergency.

The eye glasses of spectacles for old people are double convex lenses, more or less spherical, according to the age of the person, or the magnifying power required.

The common burning glasses, which are used for lighting cigars, and sometimes for kindling fires, are also convex lenses. Their effect is to concentrate to a focus, or point, the heat of the sun which falls on their whole surface; and hence the intensity of their effects is in proportion to the extent of their surfaces, and their focal lengths.

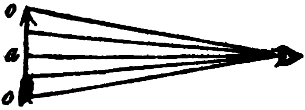
One of the largest burning glasses ever constructed, was made by Mr. Parker, of London. It was three feet in diameter, with a focal distance of three feet nine inches. But in order to increase its power still more, he employed another lens about a foot in diameter, to bring its rays to a smaller focal point. This apparatus gave a most intense degree of heat, when the sun was clear, so that 20 grains of gold were melted by it in 4 seconds, and ten grains of platina, the most infusible of all metals, in 3 seconds.

It has been explained, that the reason why the convex mirror diminishes the images of objects is, that the rays which come to the eye from the extreme parts of the object are rendered less convergent by reflection, from the convex surface, and that, in consequence, the angle of vision is made more acute.

Now, the refractive power of the convex lens has exactly the contrary effect, since by converging the rays flowing from the extremities of an object, the visual angle is rendered more obtuse, and therefore all objects seen through it appear magnified.

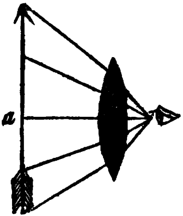
What kind of lenses are spectacle glasses for old people? What is said to be the diameter of Mr. Parker's great convex lens? What is the focal distance of this lens? What is said of its heating power? What is the visual angle?

Fig. 154.



Suppose the object *a*, fig. 154, appears to the naked eye of the length represented in the drawing. Now, as the rays coming from each end of the object, form, by their convergence at the eye, the *visual angle*, or the angle under which the object is seen, and we call objects large or small, in proportion as this angle is obtuse or acute, if therefore the object *a* be withdrawn further from the eye, it is apparent that the rays *o, o,* proceeding from its extremities, will enter the eye under a more acute angle, and therefore, that the object will appear diminished in proportion. This is the reason why things at a distance appear smaller than when near us. When near, the visual angle is increased, and when at a distance, it is diminished.

Fig. 155.



The effect of the convex lens is to increase the visual angle, by bending the rays of light coming from the object, so as to make them meet at the eye more obtusely; and hence it has the same effect, in respect to the visual angle, as bringing the object nearer the eye. This is shown by fig. 155, where it is obvious, that did the rays flowing from the extremities of the arrow meet the eye without refraction, the visual angle would be less, and therefore the object would appear shorter. Another effect of the convex lens, is to enable us to see objects nearer the eye, than without it, as will be explained under the article *vision.*

Now, as the rays of light flow from all parts of a visible object of whatever shape, so the breadth, as well as the length, is increased by the convex lens, and thus the whole object appears magnified.

Concave lens. The effect of the concave lens is directly opposite to that of the convex. In other terms, by a concave lens, parallel rays are rendered diverging, converging rays have their convergency diminished, and diverging rays have

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Why does the same object, when at a distance, appear smaller than when near? What is the effect of the convex lens on the visual angle? Why does an object appear larger through the convex lens than otherwise? What is the effect of the concave lens? What effect does this lens have upon parallel, diverging, and converging rays?

their divergency increased, according to the concavity of the lens.

These glasses, therefore, exhibit things smaller than they really are, for by diminishing the convergence of the rays coming from the extreme points of an object, the visual angle is rendered more acute, and hence the object appears diminished by this lens, for the opposite reason that it is increased by the convex lens. This will be made plain by the two following diagrams.

Fig. 156.

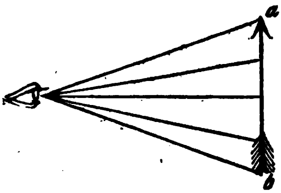
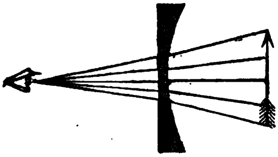


Fig. 157.



Suppose the object *a b*, fig. 156, to be placed at such a distance from the eye, as to give the rays flowing from it, the degrees of convergence represented in the figure, and suppose that the rays enter the eye under such an angle as to make the object appear two feet in length.

Now, the length of the same object, seen through the concave lens, fig. 157, will appear diminished, because the rays coming from it are bent outwards, or made less convergent by refraction, as seen in the figure, and consequently the visual angle is more acute than when the same object is seen by the naked eye. Its length, therefore, will appear less, in proportion as the rays are rendered less convergent.

The spectacle glasses of short-sighted people are concave lenses, by which the images of objects are formed further back in the eye than otherwise, as will be explained under the next article.

Vision.

In the application of the principles of optics to the explanation of natural phenomena, it is necessary to give a description of the most perfect of all optical instruments, the eye.

Why do objects appear smaller through this glass than they do to the naked eye? Explain figures 156, and 157, and show the reason why the same object appears smaller through 157. What defect in the eye requires concave lenses? What is the most perfect of all optical instruments?

Fig. 158.

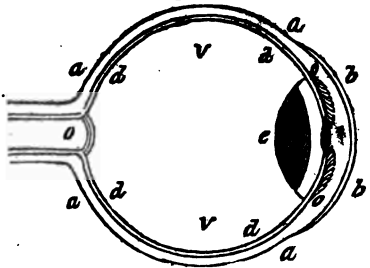


Fig. 158 is a vertical section of the human eye. Its form is nearly globular, with a slight projection or elongation in front. It consists of four coats, or membranes; namely, the *sclerotic*, the *cornea*, the *choroid*, and the *retina*. It has two fluids confined within these membranes, called the *aqueous*, and the *vitreous* humours, and one lens, called the *crystalline*. The sclerotic coat is the outer and strongest membrane, and its anterior part is well known as the *white* of the eye. This coat is marked in the figure *a*, *a*, *a*, *a*. It is joined to the cornea, *b*, *b*, which is the transparent membrane in front of the eye, through which we see. The choroid coat is a thin, delicate membrane, which lines the sclerotic coat on the inside. On the inside of this lies the *retina*, *d*, *d*, *d*, *d*, which is the innermost coat of all, and is an expansion, or continuation of the optic nerve *o*. This expansion of the optic nerve is the immediate seat of vision. The iris, *o*, *o*, is seen through the cornea, and is a thin membrane, or curtain, of different colours in different persons, and therefore gives colour to the eyes. In black eyed persons it is black, in blue eyed persons it is blue, &c. Through the iris, is a circular opening, called the *pupil*, which expands or enlarges when the light is faint, and contracts when it is too strong. The space between the iris and the cornea is called the *anterior chamber* of the eye, and is filled with the *aqueous* humor, so called from its resemblance to water. Behind the pupil and iris is situated the crystalline lens *e* which is a firm and perfectly transparent body, through which the rays of light pass from the pupil to the retina. Behind the lens is situated the *posterior chamber* of the eye, which is filled with the *vitreous humor*, *v*, *v*. This humor occupies much the largest por-

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What is the form of the human eye? How many coats, or membranes, has the eye? What are they called? How many fluids has the eye, and what are they called? What is the lens of the eye called? What coat forms the white of the eye? Describe where the several coats and humors are situated. What is the iris? What is the retina? Where is the sense of vision?

tion of the whole eye, and on it depends the shape and permanency of the organ.

From the above description of the eye, it will be easy to trace the progress of the rays of light through its several parts, and to explain in what manner vision is performed.

In doing this, we must keep in mind that the rays of light proceed from every part and point of a visible object, as heretofore stated, and that it is necessary only for a few of the rays, when compared with the whole number, to enter the eye, in order to make the object visible.

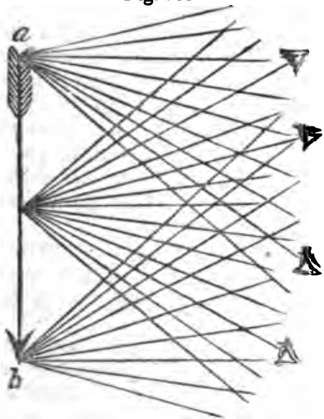

Fig. 159.

Thus, the object *a b*, fig. 159, being placed in the light, sends forth pencils of rays in all possible directions, some of which will strike the eye in any position where it is visible. These pencils of rays not only flow from the points designated in the figure, but in the same manner from every other point on the surface of a visible object. To render an object visible, therefore, it is only necessary that the eye should collect and concentrate a sufficient number of these rays on the retina to form its image there, and from this image the sensation of vision is excited.

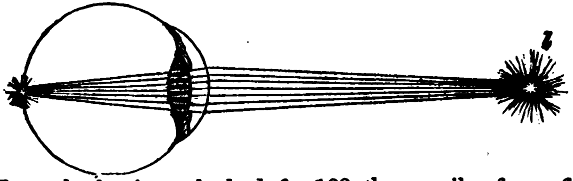

Fig. 160.

From the luminous body *l*, fig. 160, the pencils of rays flow in all directions, but it is only by those which enter the pupil, that we gain any knowledge of its existence; and even these

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What is the design of fig. 159? What is said concerning the small number of the rays which enter the eye from a visible object? Explain the design of fig. 159.

would convey to the mind no distinct idea of the object, unless they were refracted by the humours of the eye, for did these rays proceed in their natural state of divergence to the retina, the image there formed would be too extensive, and consequently too feeble to give a distinct sensation of the object.

It is, therefore, by the refracting power of the aqueous humor, and of the crystalline lens, that the pencils of rays are so concentrated as to form a perfect picture of the object on the retina.

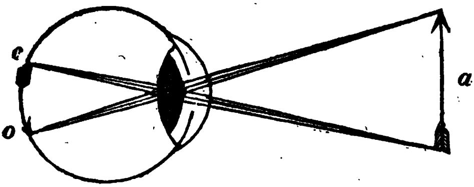
We have already seen, that when the rays of light are made to cross each other by reflection from the concave mirror, the image of the object is inverted; the same happens when the rays are made to cross each other by refraction through a convex lens. This, indeed, must be a necessary consequence of the intersection of the rays: for as light proceeds in straight lines, those rays which come from the lower part of an object, on crossing those which come from its upper part, will represent this part of the picture on the upper half of the retina, and for the same reason the upper part of the object will be painted on the lower part of the retina.

Now, all objects are represented on the retina in an inverted position; that is, what we call the upper end of a vertical object, is the lower end of its picture on the retina, and so the contrary.

This is readily proved by taking the eye of an ox, and cutting away the sclerotic coat, so as to make it transparent on the back part, next the vitreous humor. If now a piece of white paper be placed on this part of the eye, the images of objects will appear figured on the paper in an inverted position. The same effect will be produced on looking at things through an eye thus prepared; they will appear inverted.

Why would not the rays of light give a distinct idea of the object without refraction by the humors of the eye? Explain how it is that the images of objects are inverted on the retina. What experiment proves that the images of objects are inverted on the retina?

Fig. 161.



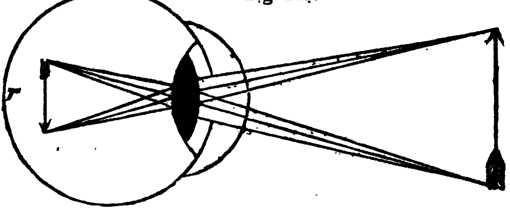
The actual position of the vertical object *a*, fig. 161, as painted on the retina, is therefore such as is represented by the figure. The rays from its upper extremity, coming in divergent lines, are converged by the crystalline lens, and fall on the retina at *o*; while those from its lower extremity, by the same law, fall on the retina at *c*.

In order that vision may be perfect, it is necessary that the images of objects should be formed precisely on the retina, and consequently, if the refractive power of the eye be too small, or too great, the image will not fall exactly on the seat of vision, but will be formed either before, or tend to form behind it. In both cases, perhaps, an outline of the object may be visible, but it will be confused and indistinct.

If the cornea is too convex, or prominent, the image will be formed before it reaches the retina, for the same reason, that of two lenses, that which is most convex will have the least focal distance. Such is the defect in the eyes of persons who are short sighted, and hence the necessity of their bringing objects as near the eye as possible, so as to make the rays converge at the greatest distance behind the crystalline lens.

The effect of uncommon convexity in the cornea on the rays of light, is shown at fig. 162, where it will be observed

Fig. 162.



that the image, instead of being formed on the retina *r*, is

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Explain fig. 161. Suppose the refractive power of the eye is too great or too little, why will vision be imperfect? If the cornea is too convex, where will the image be formed?

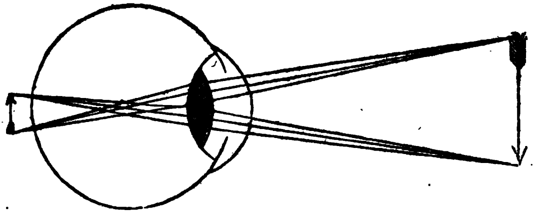
suspended in the vitreous humour, in consequence of there being too great a refractive power in the eye. It is hardly necessary to say, that in this case, vision must be very imperfectly performed.

This defect of sight is remedied by spectacles, the glasses of which are concave lenses. Such glasses, by rendering the rays of light less convergent, before they reach the eye, counteract the too great convergent power of the cornea and lens, and thus throw the image on the retina.

If, on the contrary, the humours of the eye, in consequence of age or any other cause, have become less in quantity than ordinary, the eye ball will not be sufficiently distended, and the cornea will become too flat, or not sufficiently convex, to make the rays of light meet at the proper place, and the image will therefore tend to be formed beyond the retina, instead of before it, as in the other case. Hence aged people, who labor under this defect of vision, cannot see distinctly at ordinary distances, but are obliged to remove the object as far from the eye as possible, so as to make its refractive power bring the image within the seat of vision.

The defect arising from this cause is represented by figure 163, where it will be observed that the image is formed behind the retina, showing that the convexity of the cornea is not sufficient to bring the image within the seat of distinct vision. This imperfection of sight is common to aged persons, and is corrected in a greater or less degree by double convex lenses, such as the common spectacle glasses. Such glasses, by causing the rays of light to converge, before they meet the eye, as-

Fig. 163.



How is the sight improved when the cornea is too convex? How do such lenses act to improve the sight? Where do the rays tend to meet when the cornea is not sufficiently convex? How is vision assisted when the eye wants convexity? How do convex lenses help the sight of aged people?

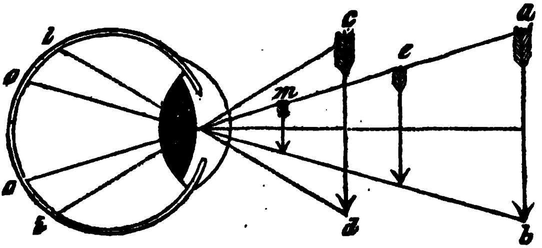
sist the refractive power of the crystalline lens, and thus bring the focus, or image, within the sphere of vision.

It has been considered difficult to account for the reason why we see objects erect, when they are painted on the retina inverted, and many learned theories have been written to explain this fact. But it is most probable that this is owing to habit, and that the image, at the bottom of the eye, has no relation to the terms above and below, but to the position of our bodies, and other things which surround us. The term *perpendicular*, and the idea which it conveys to the mind, is merely relative; but when applied to an object supported by the earth, and extending towards the skies, we call the body erect because it coincides with the position of our own bodies, and we see it erect for the same reason. Had we been taught to read by turning our books upside down, what we now call the upper part of the book would have been its under part, and that reading would have been as easy in that position as in any other, is plain from the fact that printers read their type, when set up, as readily as they do its impressions on paper.

Angle of Vision. The angle under which the rays of light, coming from the extremities of an object, cross each other at the eye, bears a proportion directly to the length, and inversely to the distance of the object.

Suppose the object *a*, *b*, fig. 164, to be four feet long, and to be placed ten feet from the eye, then the rays flowing from its extremities, would intersect each other at the eye, under a given angle, which will always be the same when the object

Fig. 164.



Why do we see things erect, when the images are inverted on the retina? What is the visual angle?

is at the same distance. If the object be gradually moved towards the eye, to the place *c d*, then the angle will be gradually increased in quantity, and the object will appear larger, since its image on the retina will be increased in length in the proportion as the lines *i i* are wider apart than *o o*. On the contrary, were *a b* removed to a greater distance from the first position, it is obvious that the angle would be diminished in proportion.

The lines thus proceeding from the extremities of an object, and representing the rays of light, form an angle at the eye, which is called the *visual angle*, or the angle under which things are seen. The lines *a n b* therefore form one visual angle, and the lines *c n d* another visual angle.

We see from this investigation, that the apparent magnitude of objects depending on the angles of vision, will vary according to their distances from the eye, and that these magnitudes diminish in a proportion inversely as their distances increase. We learn also, from the same principles, that objects of different magnitudes may be so placed, with respect to the eye, as to give the same visual angle, and thus to make their apparent magnitudes equal. Thus the three arrows *a*, *e*, and *m* though differing so much in length, are all seen under the same visual angle.

In the apparent magnitude of objects seen through a lens or when their images reach the eye by reflection from a mirror, our senses are chiefly, if not entirely guided by the angle of vision. In forming our judgment of the sizes of distant objects, whose magnitudes were before unknown, we are also guided more or less by the visual angle, though in this case we do not depend entirely on the sense of vision. Thus if we see two balloons floating in the air, one of which is larger than the other, we judge of their comparative magnitudes by the difference in their visual angles, and of their real magnitudes by the same angles, and the distance we suppose them to be from us.

But when the object is near us, and seen with the naked eye, we then judge of its magnitude by our experience, and no-

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How may the visual angle of the same object be increased or diminished? When do objects of different magnitudes form the same visual angle? Explain fig. 164. Under what circumstances is our sense of vision guided entirely by the visual angle? How do we judge of the magnitudes of distant objects? How do we judge of the comparative size of objects near us?

entirely by the visual angle. Thus, the three arrows, *a*, *e*, *m*, fig. 164, all of them make the same angle on the eye, and yet we know by further examination, that they are all of different lengths. And so the two arrows *a b*, and *c d*, though seen under different visual angles, will appear of the same size, because experience has taught us that this difference depends only on the comparative distance of the two objects.

As the visual angle diminishes inversely in proportion as the distance of the object increases, so when the distance is so great as to make the angle too minute to be perceptible to the eye, then the object becomes invisible. Thus, when we watch an eagle, flying from us, the angle of vision is gradually diminished, until the rays proceeding from the bird form an image on the retina too small to excite sensation, and then we say, the eagle has flown out of sight.

The same principle holds with respect to objects which are near the eye, but are too small to form an image on the retina, which is perceptible to the senses. Such objects to the naked eye, are of course invisible, but when the visual angle is enlarged, by means of a convex lens, they become visible; that is, their images on the retina excite sensation.

The actual size of an image on the retina, capable of exciting sensation, and consequently of producing vision, may be too small for us to appreciate by any of our other senses; for when we consider how much smaller the image must be than the object, and that a human hair can be distinguished by the naked eye at the distance of twenty or thirty feet, we must suppose that the retina is endowed with the most delicate sensibility, to be excited by a cause so minute. It has been estimated that the image of a man, on the retina, seen at the distance of a mile, is not more than the five thousandth part of an inch in length.

On the contrary, if the object be brought too near the eye, its image becomes confused and indistinct, because the rays flowing from it, fall on the crystalline lens in a state too divergent to be refracted to a focus on the retina.

When does a retreating object become invisible to the eye? How does a convex lens act to make us see objects which are invisible without it? What is said of the actual size of an image on the retina? Why are objects indistinct, when brought too near the eye?

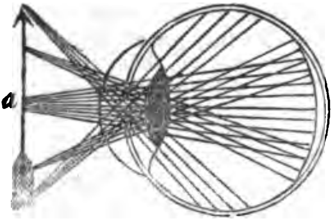


Fig. 165.

This will be apparent by fig. 165, where we suppose that the object *a*, is brought within an inch or two of the eye, and that the rays proceeding from it enter the pupil so obliquely as not to be refracted by the lens, so as to form a distinct image.

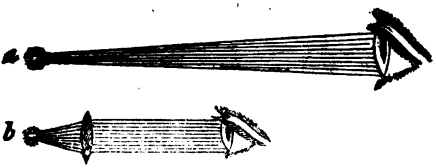
Could we see objects distinctly at the shortest distance, we should be able to examine things that are now invisible, since the visual angle would then be increased, and consequently the image on the retina enlarged, in proportion as objects were brought near the eye. This is proved by intercepting the most divergent rays; in which case an object may be brought near the eye, and will then appear greatly magnified. Make a small orifice, as a pinhole, through a piece of dark colored paper, and then look through the orifice at small objects, such as the letters of a printed book. The letters will appear much magnified. The rays, in this case, are refracted to a focus, on the retina, because the small orifice prevents those which are most divergent from entering the eye, so that notwithstanding the nearness of the object, the rays which form the image are nearly parallel.

Optical Instruments.

Single Microscope. The principle of the single microscope, or convex lens, will be readily understood, if the pupil will remember what has been said on the refraction of lenses, in connexion with the facts just stated. For, the reason why objects appear magnified through a convex lens, is not only because the visual angle is increased, but because when brought near the eye, the diverging rays from the object are rendered parallel by the lens, and are thus thrown into a condition to be brought to a focus in the proper place by the humors.

Suppose objects could be seen distinctly within an inch or two of the eye, how would their dimensions be affected? How is it proved that objects placed near the eye are magnified? How does a small orifice enable us to see an object distinctly near the eye? Why does a convex lens make an object distinct when near the eye?

Fig. 166.



Let *a*, fig. 166, be the distance at which an object can be seen distinctly, and *b*, the distance at which the same object is seen through the lens, and suppose the distance of *a*, from the eye, be twice that of *b*. Then, because the object is at half the distance that it was before, it will appear twice as large; and had it been seen one third, one fourth, or one tenth its former distance, it would have been magnified three, four, or ten times, and consequently its surface would be increased 9, 16, or 100 times.

The most powerful single microscopes are made of minute globules of glass, which are formed by melting the ends of a few threads of spun glass in a candle. Small globules of water placed in an orifice through a piece of tin, or other thin substance, will also make very powerful microscopes. In these minute lenses, the focal distance is only a tenth or twelfth part of an inch from the lens, and therefore the eye, as well as the object to be magnified, must be brought very near the instrument.

The *Compound Microscope* consists of two convex lenses, by one of which the image is formed within the tube of the instrument, and by the other this image is magnified, as seen by the eye; so that by this instrument the object itself is not seen, as with the single microscope, but we see only its magnified image.

The small lens placed near the object, and by which its image is formed within the tube, is called the *object glass*, while the larger one, through which the image is seen, is called the *eye glass*.

This arrangement is represented at fig. 167. The object *a* is placed a little beyond the focus of the object glass *b*, by which an inverted and enlarged image of it is formed within the instrument at *c*. This image is seen through the eye

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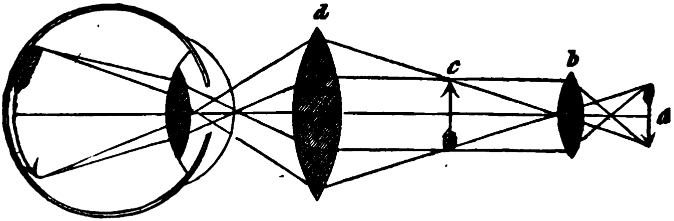
Explain fig. 166. How are the most powerful single microscopes made? How many lenses form the compound microscope? Which is the object and which the eye glass? Is the object seen with this instrument, or only its image?

Fig. 167.



glass *d*, by which it is again magnified, and it is at last figured on the retina in its original position.

These glasses are set in a case of brass, the object glass being made to take out, so that others of different magnifying powers may be used, as occasion requires.

The *Solar Microscope* consists of two lenses, one of which is called the *condenser*, because it is employed to concentrate the rays of the sun, in order to illuminate more strongly the object to be magnified. The other is a double convex lens, of considerable magnifying power, by which the image is formed. In addition to these lenses, there is a plain mirror, or piece of common looking-glass, which can be moved in any direction, and which reflects the rays of the sun on the condenser.

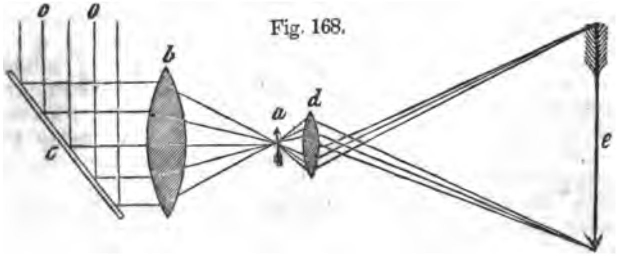


Fig. 168.

The object *a*, fig. 168, being placed nearly in the focus of the condenser *b*, is strongly illuminated, in consequence of the rays of the sun being thrown on *b*, by the mirror *c*. The object is not placed exactly in the focus of the condenser, because, in most cases, it would be soon destroyed by its heat,

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Explain fig. 167, and show where the image is formed in this tube. How many lenses has the solar microscope? Why is one of the lenses of the solar microscope called the condenser? Describe the uses of the two lenses and the reflector.

and because the focal point would illuminate only a small extent of surface, but may be exactly in the focus of the small lens *d*, by which no such accident can happen. The lines *o o*, represent the incident rays of the sun, which are reflected on the condenser.

When the solar microscope is used, the room is darkened, the only light admitted being that which is thrown on the object by the condenser, which light passing through the small lens, gives the magnified shadow *e*, of the small object *a*, on the wall of the room, or on a screen. The tube containing the two lenses is passed through the window of the room, the reflector remaining outside.

In the ordinary use of this instrument, the object itself is not seen, but only its shadow on the screen, and it is not designed for the examination of opaque objects.

When the small lens of the solar microscope is of great magnifying power, it presents some of the most striking and curious of optical phenomena. The shadows of mites from cheese, or figs, appear nearly two feet in length, presenting an appearance exceedingly formidable and disgusting; and the insects from common vinegar appear eight or ten feet long, and in perpetual motion, resembling so many huge serpents.

Telescope. The *telescope* is an optical instrument, employed to view distant bodies, and, in effect, to bring them nearer the eye, by increasing the apparent angles under which such objects are seen.

These instruments are of two kinds, namely, *refracting*, and *reflecting* telescopes. In the first kind, the image of the object is seen with the eye directed towards it; in the second kind, the image is seen by reflection from a mirror, while the back is towards the object, or by a double reflection, with the face towards the object.

The telescope is the most important of all optical instruments, since it unfolds the wonders of other worlds, and gives us the means of calculating the distances of the heavenly bodies, and of explaining their phenomena for astronomical and nautical purposes.

The principle of the telescope will be readily comprehended after what has been said concerning the compound microscope, for the two instruments differ chiefly in respect to the

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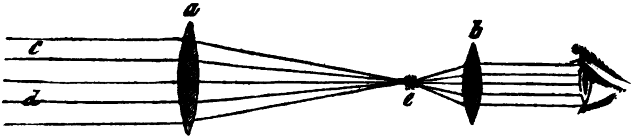
Is the object, or only the shadow, seen by this instrument? What is a telescope? How many kinds of telescopes are mentioned? What is the difference between them? In what respect does the refracting telescope differ from the compound microscope?

place of the object lens, that of the microscope having a short, while that of the telescope has a long, focal distance.

Refracting Telescope. The most simple refracting telescope consists of a tube, containing two convex lenses, the one having a long, and the other a short, focal distance. (The focal distance of a double convex lens, it will be remembered, is nearly the centre of a sphere, of which it is a part.) These two lenses are placed in the tube, at a distance from each other equal to the sum of their two focal distances.

Fig. 169.



Thus, if the focus of the object glass *a*, fig. 169, be eight inches, and that of the eye glass *b* two inches, then the distance of the sums of the foci will be ten inches, and, therefore, the two lenses must be placed ten inches apart; and the same rule is observed, whatever may be the focal lengths of any two lenses.

Now, to understand the effect of this arrangement, suppose the rays of light, *c d*, coming from a distant object, as a star, to fall on the object glass *a*, in parallel lines, and to be refracted by the lens to a focus at *e*, where the image of the star will be represented. This image is then magnified by the eye glass *b*, and thus, in effect, is brought near the eye.

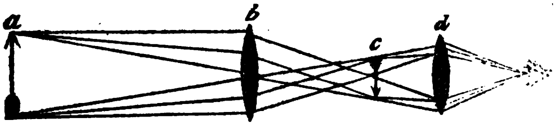
All that is effected by the telescope, therefore, is to form an image of a distant object, by means of the object lens, and then to assist the eye in viewing this image as nearly as possible by the eye lens.

It is, however, necessary here to state, that by the last figure, the principle only of the telescope is intended to be explained, for in the common instrument, with only two glasses, the image appears to the eye inverted.

The reason of this will be seen by the next figure, where the direction of the rays of light will show the position of the image.

How is the most simple refracting telescope formed? Which is the object, and which the eye lens, in fig. 169? What is the rule by which the distance of the two glasses apart is found? How do the two glasses act, to bring an object near the eye?

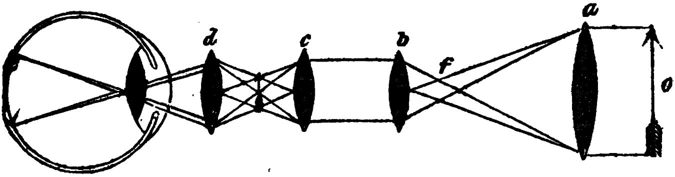
Fig. 170.



Suppose *a*, fig. 170, to be a distant object, from which pencils of rays flow from every point toward the object lens *b*. The image of *a*, in consequence of the refraction of the rays by the object lens, is inverted at *c*, which is the focus of the eye glass *d*, and through which the image is then seen, still inverted.

The inversion of the object is of little consequence when the instrument is employed for astronomical purposes, for since the forms of the heavenly bodies are spherical, their positions, in this respect, do not affect their general appearance. But for terrestrial purposes, this is manifestly a great defect, and therefore those constructed for such purposes, as ship, or spy glasses, have two additional lenses, by means of which, the images are made to appear in the same position as the objects. These are called double telescopes.

Fig. 171.



Such a telescope s represented at fig. 171, and consists of an object glass *a*, and three eye glasses, *b*, *c*, and *d*. The eye glasses are placed at equal distances from each other, so that the focus of one may meet that of the other, and thus the image formed by the object lens, will be transmitted through the other three lenses, to the eye. The rays coming from the object *o*, cross each other at the focus of the object lens, and thus form an inverted image at *f*. This image being also in the

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Explain fig. 170, and show how the object comes to be inverted by the two lenses. How is the inversion of the object corrected? Explain fig. 171, and show why the two additional lenses make the image of the object erect.

focus of the first eye glass, *b*, the rays having passed through this glass become parallel, for, we have seen, in another place, that diverging rays are rendered parallel by refraction through a convex lens. The rays, therefore, pass parallel to the next lens, *c*, by which they are made to converge, and cross each other, and thus the image is inverted, and made to assume the original position of the object *o*. Lastly, this image, being in the focus of the eye glass *d*, is seen in the natural position, or in that of the object.

The apparent magnitude of the object is not changed by these two additional glasses, but depends, as in fig. 170, on the magnifying power of the eye and object lenses; the two glasses being added merely for the purpose of making the image appear erect.

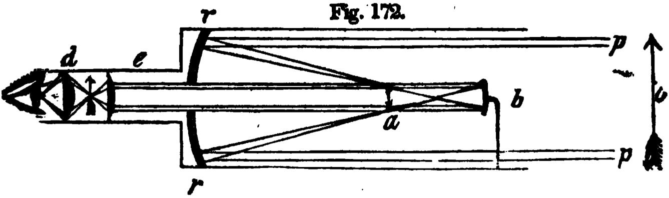
It is found that an eye glass of very high magnifying power cannot be employed in the refracting telescope, because it disperses the rays of light, so that the image becomes indistinct. Many experiments were formerly made with a view to obviate this difficulty, and among these it was found that increasing the focal distance of the object lens, was the most efficacious. But this was attended with great inconvenience, and expense, on account of the length of tube which this mode required. These experiments were, however, discontinued, and the refracting telescope itself chiefly laid aside for astronomical purposes, in consequence of the discovery of the reflecting telescope.

Reflecting Telescope. The common reflecting telescope consists of a large tube, containing two concave reflecting mirrors, of different sizes, and two eye glasses. The object is first reflected from the large mirror to the small one, and from the small one, through the two eye glasses, where it is then seen.

In comparing the advantages of the two instruments, it need only be stated, that the refracting telescope, with a focal length of a thousand feet, if it could be used, would not magnify distinctly more than a thousand times, while a reflecting telescope, only eight or nine feet long, will magnify with distinctness twelve hundred times.

Does the addition of these two lenses make any difference with the apparent magnitude of the object? Why cannot a highly magnifying eye glass be used in the telescope? What is the most efficacious means of increasing the power of the refracting telescope? How many lenses and mirrors form the reflecting telescope? What are the advantages of the reflecting over the refracting telescope?

Fig. 172.



The principle and construction of the reflecting telescope will be understood by fig. 172. Suppose the object *o* to be at such a distance, that the rays of light from it pass in parallel lines, *p*, *p*, to the great reflector, *r*, *r*. This reflector being concave, the rays are converged by reflection, and cross each other at *a*, by which the image is inverted. The rays then pass to the small mirror, *b*, which being also concave, they are thrown back in nearly parallel lines, and having passed the aperture in the centre of the great mirror, fall on the plano-convex lens *e*. By this lens they are refracted to a focus, and cross each other between *e* and *d*, and thus the image is again inverted, and brought to its orignal position, or in the position of the object. The rays then, passing the second eye glass, form the image of the object on the retina.

The large mirror in this instrument is fixed, but the small one moves backwards and forwards, by means of a screw, so as to adjust the image to the eyes of different persons. Both mirrors are made of a composition, consisting of several metals melted together.

One great advantage which the reflecting telescope possesses over the refracting, appears to be, that it admits of an eye glass of shorter focal distance, and consequently, of greater magnifying power. The convex object glass of the refracting instrument, does not form a perfect image of the object, since some of the rays are dispersed, and others colored by refraction. This difficulty does not occur in the reflected image from the metallic mirror of the reflecting telescope, and consequently it may be distinctly seen, when more highly magnified.

The instrument just described is called "*Gregory's telescope*," because some parts of the arrangement were invented by Dr. Gregory.

Explain fig. 172, and show the course of the rays from the object to the eye.
Why is the small mirror in this instrument made to move by means of a screw?
What is the advantage of the reflecting telescope in respect to the eye glass?
Why is the telescope with two reflectors called Gregory's telescope?

In the telescope made by Dr. Herschel, the object is reflected by a mirror, as in that of Dr. Gregory. But the second, or small reflector, is not employed, the image being seen through a convex lens, placed so as to magnify the image of the large mirror, so that the observer stands with his back towards the object.

The magnifying power of this instrument is the same as that of Dr. Gregory's, but the image appears brighter, because there is no second reflection; for every reflection renders the image fainter, since no mirror is so perfect as to throw back all the rays which fall upon its surface.

In Dr. Herschel's grand telescope, the largest ever constructed, the reflector was 48 inches in diameter, and had a focal distance of 40 feet. This reflector was three and a half inches thick, and weighed 2000 pounds. Now, since the focus of a concave mirror is at the distance of one half the semidiameter of the sphere, of which it is a section, Dr. Herschel's reflector having a focal distance of 40 feet, formed a part of a sphere of 160 feet in diameter.

This great instrument was begun in 1785, and finished four years afterwards. The frame by which this wonder to all astronomers was supported, having decayed, it was taken down in 1822, and another of 20 feet focus, with a reflector of 18 inches in diameter, erected in its place, by Herschel's son.

The largest Herschel's telescope now in existence is that of Greenwich observatory, in England. This has a concave reflector of 15 inches in diameter, with a focal length of 25 feet, and was erected in 1820.

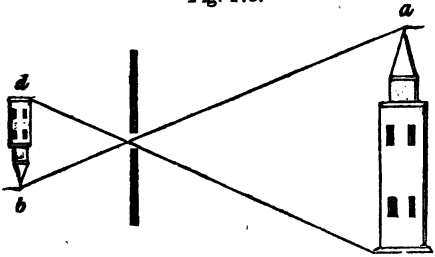
Camera Obscura. Camera obscura strictly signifies a darkened chamber, because the room must be darkened, in order to observe its effects.

To witness the phenomena of this instrument, let a room be closed in every direction, so as to exclude the light. Then from an aperture, say of an inch in diameter, admit a single beam of light, and the images of external things, such as trees, and houses, and persons walking the streets, will be seen inverted on the wall opposite to where the light is admitted, or on a screen of white paper, placed before the aperture.

How does this instrument differ from Dr. Herschel's telescope? What was the focal distance and diameter of the mirror in Dr. Herschel's great telescope? Where is the largest Herschel's telescope now in existence? What is the diameter and focal distance of the reflector of this telescope? Describe the phenomena of the camera obscura.

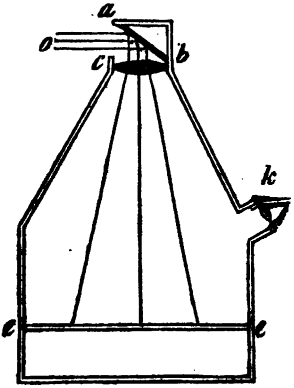
The reason why the image is inverted, will be obvious, when it is remembered that the rays proceeding from the extremities of the object must converge in order to pass through the small aperture; and as the rays of light always proceed in straight lines, they must cross each other at the point of admission, as explained under the article *Vision*.

Fig. 173.



Thus the pencil *a*, fig. 173, coming from the upper part of the tower, and proceeding straight will represent the image of that part at *b*, while the lower part *c*, for the same reason will be represented at *d*. If a convex lens, with a short tube, be placed in the aperture through which the light passes into the room, the images of things will be much more perfect, and their colors more brilliant.

Fig. 174.



This instrument is sometimes employed by painters, in order to obtain an exact delineation of a landscape, an outline of the image being easily taken, with a pencil, when the image is thrown on a sheet of paper.

There are several modifications of this machine, and among them the *revolving* camera obscura is the most interesting.

It consists of a small house, fig. 174, with a plane reflector, *a b*, and a convex lens, *c b*, placed at its top. The reflector is fixed at an angle of 45 degrees with the horizon, so as to reflect

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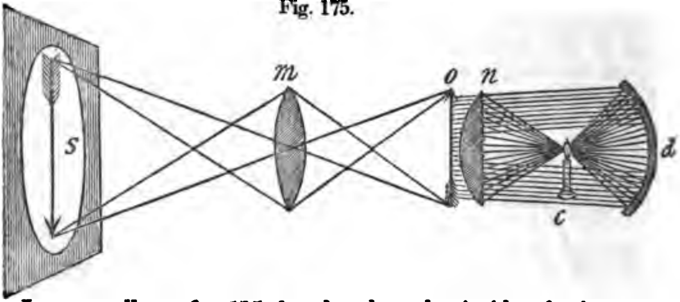
Why is the image formed by the camera obscura inverted? How may an outline of the image formed by the camera obscura be taken? Describe the revolving camera obscura.

the rays of light perpendicularly downwards, and is made to revolve quite around, in either direction, by pulling a string.

Now suppose the small house to be placed in the open air, with the mirror *a b*, turned towards the east, then the rays of light flowing from the objects in that direction, will strike the mirror in the direction of the lines *o*, and be reflected down through the convex lens *c b*, to the table *e e*, where they will form in miniature a most perfect and beautiful picture of the landscape in that direction. Then by making the reflector revolve, another portion of the landscape may be seen, and thus the objects in all directions can be viewed at *k* without changing the place of the instrument.

The *Magic Lantern*. The Magic Lantern is a microscope, on the same principle as the solar microscope. But instead of being used to magnify natural objects, it is commonly employed for amusement, by casting the shadows of small transparent paintings done on glass, upon a screen placed at a proper distance.

Fig. 175.



Let a candle, *c*, fig. 175, be placed on the inside of a box, or tube, so that its light may pass through the plano-convex lens *n*, and strongly illuminate the object *o*. This object is generally a small transparent painting on a slip of glass, which slides through an opening in the tube. In order to show the figures in the erect position, these paintings are inverted, since their shadows are again inverted by the refraction of the convex lens *m*.

In some of these instruments, there is a concave mirror, *d*, by which the object, *o*, is more strongly illuminated than it would be by the lamp alone. The object is magnified by the

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What is the magic lantern? For what purpose is this instrument employed? Describe the construction and effect of the magic lantern.

double convex lens, *m*, which is moveable in the tube by a screw, so that its focus can be adjusted to the required distance. Lastly, there is a screen of white cloth, placed at the proper distance, on which the image, or shadow of the picture, is seen greatly magnified.

The pictures, being of various colors, and so transparent, that the light of the lamp shines through them, the shadows are also of various colors, and thus soldiers and horsemen are represented in their proper costume.

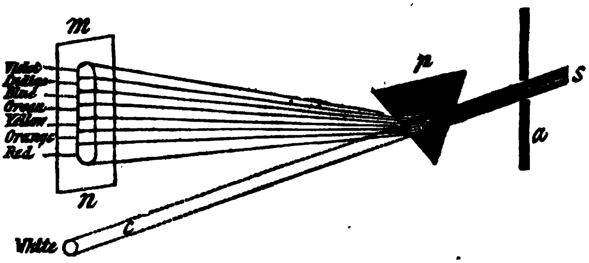
Chromatics, or the philosophy of Colors.

We have thus far considered light as a simple substance, and have supposed that all its parts were equally refracted, in its passage through the several lenses described. But it will now be shown that light is a compound body, and that each of its rays, which to us appear white, is composed of several colors, and that each color suffers a different degree of refraction, when the rays of light pass through a piece of glass, of a certain shape.

The discovery, that light is a compound substance, and that it may be decomposed, or separated into parts, was made by Sir Isaac Newton.

If a ray, proceeding from the sun, be admitted into a darkened chamber, through an aperture in the window shutter, and allowed to pass through a triangular shaped piece of glass, called a *prism*, the light will be decomposed, and instead of a spot of white light, there will be seen on the opposite wall, a most brilliant display of colors, including all those which are seen in the rainbow.

Fig. 176.



Who made the discovery that light is a compound substance? In what manner and by what means, is light decomposed?

Suppose *s*, fig. 176, to be a ray from the sun, admitted through the window shutter *a*, in such a direction as to fall on the floor at *c*, where it would form a round, white spot. Now, on interposing the prism *p*, the ray will be refracted, and at the same time decomposed, and will form on the screen *m n*, an oblong figure, containing seven colors, which will be situated in respect to each other, as named in the figure.

It may be observed that of all the colors, the red is *least* refracted, or is thrown the smallest distance from the direction of the original sun beam, and that the violet is *most* refracted, or bent out of that direction.

The oblong image containing the colored rays, is called the *solar* or *prismatic spectrum*.

That the rays of the sun are composed of the seven colors above named, is sufficiently evident by the fact, that such a ray is divided into these several colors by passing through the prism, but in addition to this proof, it is found by experiment, that if these several colors be blended or mixed together, white will be the result.

This may be done by mixing together seven powders, whose colors represent the prismatic colors, and whose quantities are to each other, as the spaces occupied by each color in the spectrum. When this is done, it will be found that the resulting color will be a greyish white. A still more satisfactory proof that these seven colors form white, when united, is obtained by causing the solar spectrum to pass through a lens, by which they are brought to a focus, when it is found that the focus will be the same color as it would be from the original rays of the sun.

From the oblong shape of the solar spectrum, we learn that each of the colored rays is refracted in a different degree by passing through the same medium, and consequently that each ray has a refractive power of its own. Thus from the red to the violet, each ray in succession, is refracted more than the other.

The prism is not the only instrument by which light can be

What are the prismatic colors, and how do they succeed each other in the spectrum? Which color is refracted most, and which least? When the several prismatic colors are blended, what color is the result? When the solar spectrum is made to pass through a lens, what is the color of the focus? How do we learn that each colored ray has a refractive power of its own? By what other means beside the prism, can the rays of light be decomposed?

decomposed. A soap bubble blown up in the sun will display most of the prismatic colors. This is accounted for by supposing that the sides of the bubble vary in thickness, and that the rays of light are decomposed by these variations. The unequal surface of *mother of pearl*, and many other shells, send forth colored rays on the same principle.

Two surfaces of polished glass, when pressed together, will also decompose the light. Rings of colored light will be observed round the point of contact between the two surfaces, and their number may be increased or diminished by the degrees of pressure. Two pieces of common looking glass, pressed together with the fingers, will display most of the prismatic colors.

A variety of substances, when thrown into the form of the triangular prism, will decompose the rays of light, as well as a prism of glass. A very common instrument for this purpose is made by putting together three pieces of plate glass, in form of a prism. The ends may be made of wood, and the edges cemented with putty, so as to make the whole water tight. When this is filled with water and held before a sun beam, the solar spectrum will be formed, displaying the same colors, and in the same order, as that above described.

In making experiments with prisms filled with different kinds of liquids, it has been found that one liquid will make the spectrum longer than another; that is, the red and violet rays, which form the extremes of the spectrum, will be thrown farther apart by one fluid, than by another. For example, if the prism be filled with oil of cassia, the spectrum formed by it will be more than twice as long as that formed by a prism of solid glass. The oil of cassia is therefore said to disperse the rays of light more than glass, and hence to have a greater *dispersive power*.

The *Rainbow*. The rainbow was a phenomenon, for which the ancients were entirely unable to account; but after the discovery that light is a compound principle, and that its colors may be separated by various substances, the solution of this phenomenon became easy.

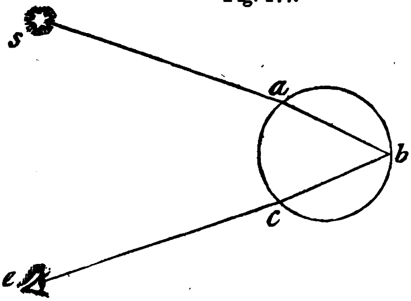
Sir Isaac Newton, after his great discovery of the compound

How may light be decomposed by two pieces of glass? Of what substances may prisms be formed, besides glass? What is said of some liquids making the spectrum larger than others? What is said of oil of cassia, in this respect? What discovery preceded the explanation of the rainbow?

nature of light, and the different refrangibility of the colored rays, was able to explain the rainbow on optical principles.

If a glass globe be suspended in a room, where the rays of the sun can fall upon it, the light will be decomposed, or separated into several colored rays, in the same manner as is done by the prism. A well defined spectrum will not, however, be formed by the globe, because its shape is such as to disperse some of the rays, and converge others; but the eye, by taking different positions in respect to the globe, will observe the various prismatic colors. Transparent bodies, such as glass and water, reflect the rays of light from both their surfaces, but chiefly from the second surface. That is, if a plate of naked glass be placed so as to reflect the image of the sun, or of a lamp, to the eye, the most distinct image will come from the second surface, or that most distant from the eye. The great brilliancy of the diamond is owing to this cause. It will be understood directly, how this principle applies to the explanation of the rainbow.

Fig. 177.



Suppose the circle *a b c*, fig. 177, to represent a globe or a drop of rain, for each drop of rain, as it falls through the air, is a small globe of water. Suppose, also, that the sun is at *s*, and the eye of the spectator at *e*. Now, it has already been stated, that from a single globe, the whole solar spectrum is not seen in the same position, but that the different colors are seen from different places. Suppose then, that a ray of light from the sun *s*, on entering the globe at *a*, is separated into its primary colors, and at the same time the red ray, which is the least refrangible, is refracted in the line from *a* to *b*. From the second, or inner surface of the globe, it would be reflected to *c*, the angle of re-

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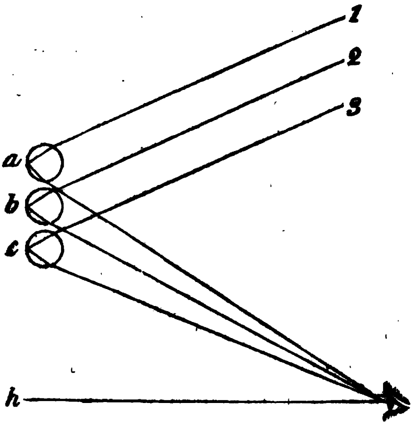
Who first explained the rainbow on optical principles? Why does not a glass globe form a well defined spectrum? From which surface do transparent bodies chiefly reflect the light? Explain fig. 177, and show the different refractions, and the reflection concerned in forming the rainbow.

flection being equal to that of incidence. On passing out of the globe, its refraction at *c*, would be just equal to the refraction of the incident ray at *a*, and therefore the red ray would fall on the eye at *e*. All the other colored rays would follow the same law, but because the angles of incidence and those of reflection are equal, and because the colored rays are separated from each other, by unequal refraction, it is obvious that if the red ray entered the eye at *e*, none of the other colored rays could be seen from the same point.

From this it is evident, that if the eye of the spectator is moved to another position he will not see the red ray coming from the same drop of rain, but only the blue, and if to another position, the green, and so of all the others. But in a shower of rain, there are drops at all heights, and distances, and though they perpetually change their places, in respect to the sun and the eye, as they fall, still there will be many which will be in such a position as to reflect the red rays to the eye, and as many more to reflect the yellow rays, and so of all the other colors.

Fig. 178.



This will be made obvious by fig. 178, where, to avoid confusion, we will suppose that only three drops of rain, and consequently, only three colors are to be seen.

The numbers 1, 2, 3, are the rays of the sun, proceeding to the drops *a*, *b*, *c*, and from which these rays are reflected to the eye, making different angles with the horizontal line *h*, because one colored

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In the case supposed, why will only the red ray meet the eye? Suppose a person looking at a rainbow moves his eye, will he see the same colors from the same drop of rain? Explain fig. 178, and show why we see different colors from different drops of rain.

ray is refracted more than another. Now suppose the red ray only reaches the eye from the drop *a*, the green from the drop *b*, and the violet from the drop *c*, then the spectator would see a minute rainbow of three colors. But during a shower of rain, all the drops which are in the position of *a*, in respect to the eye, would send forth red rays, and no other, while those in the position of *b*, would emit green rays, and no other, and those in the position of *c*, violet rays, and so of all the other prismatic colors. Each circle of colors of which the rainbow is formed, is therefore composed of reflections from a vast number of different drops of rain, and the reason why these colors are distinct to our senses, is, that we see only one color from a single drop, with the eye in the same position. It follows, then, that if we change our position, while looking at a rainbow, we still see a bow, but not the same as before, and hence, if there are many spectators, they will all see a different rainbow, though it appears to be the same.

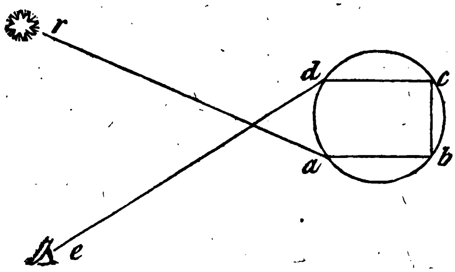
There are often seen two rainbows, the one formed as above described, and the other which is fainter, appearing on the outside, or above this. The secondary bow, as this last is called, always has its order of colors the reverse of the primary one. Thus the colors of the primary bow, beginning with its upper, or outermost portion, are red, orange, yellow, &c. the lowest, or innermost portion being violet, while the secondary bow, beginning with the same corresponding part, is colored, violet, indigo, &c. the lowest, or innermost circle being red.

In the primary bow we have seen, that the colored rays arrive at the eye after two refractions, and one reflection. In the secondary bow, the rays reach the eye after two refractions, and two reflections, and the order of the colors is reversed, because in this case, the rays of light enter the lower part of the drop, instead of the upper part, as in the primary bow. The reason why the colors are fainter in the secondary than in the primary bow is, because a part of the light is lost or dispersed, at each reflection, and there being two reflections, by which this bow is formed, instead of one, as in the primary, the difference in brilliancy is very obvious.

Do several persons see the same rainbow at the same time? Explain the reason of this. How are the colors of the primary and secondary bows arranged in respect to each other? How many refractions and reflections produce the secondary bow? Why is the secondary bow less brilliant than the primary?

The direction of a single ray, showing how the secondary bow is formed, will be seen at fig. 179.

Fig. 179.



The ray *r*, from the sun, enters the drop of water at *a*, and is *refracted* to *b*, then *reflected* to *c*, then again reflected to *d*, where it suffers another refraction, and lastly, passes to the eye of the spectator at *e*.

The rainbow, being the consequence of the refracted and reflected rays of the sun, is never seen, except when the sun and the spectator are in similar directions, in respect to the shower. It assumes the form of a semicircle, because it is only at certain angles that the refracted rays are visible to the eye.

Of the colors of things. The light of the sun, we have seen, may be separated into seven primary rays, each of which has a color of its own, and which is different from that of the others. In the objects which surround us, both natural and artificial, we observe a great variety of colors, which differ from those composing the solar spectrum, and hence one might be led to believe that both nature and art afford colors different from those afforded by the decomposition of the solar rays. But it must be remembered, that the solar spectrum contains only the *primary* colors of nature, and that by mixing these colors in various proportions with each other, an indefinite variety of tints, all differing from their primaries, may be obtained.

It appears that the colors of all bodies depend on some peculiar property of their surfaces, in consequence of which, they absorb some of the colored rays, and reflect the others. Had the surfaces of all bodies the property of reflecting the

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Why are the colors of things different from those of the solar spectrum? On what do the colors of bodies depend? Suppose all bodies reflected the same ray what would be the consequence, in regard to color?

same ray only, all nature would display the monotony of a single color, and our senses would never have known the charms of that variety which we now behold.

All bodies appear of the color of that ray, or of a tint depending on the several rays which it reflects, while all the other rays are absorbed, or, in other terms, are not reflected. *Black* and *white*, therefore, in a philosophical sense, cannot be considered as colors, since the first arises from the absorption of all the rays, and the reflection of none, and the last is produced by the reflection of all the rays, and the absorption of none. But in all colors, or shades of color, the rays only are reflected, of which the color is composed. Thus the color of grass, and the leaves of plants is green, because the surfaces of these substances reflect only the green rays, and absorb all the others. For the same reason the rose is red, the violet blue, and so of all colored substances, every one throwing out the ray of its own color, and absorbing all the others.

To account for such a variety of colors as we see in different bodies, it is supposed that all substances, when made sufficiently thin, are transparent, and consequently, that they transmit through their surfaces, or absorb, certain rays of light, while other rays are thrown back, or reflected, as above described. Gold, for example, may be beat so thin as to transmit some of the rays of light, and the same is true of several of the other metals, which are capable of being hammered into thin leaves. It is therefore most probable, that all the metals, could they be made sufficiently thin, would permit the rays of light to pass through them. Most, if not quite all mineral substances, though in the mass they may seem quite opaque, admit the light through their edges, when broken, and almost every kind of wood, when made no thinner than writing paper, becomes translucent. Thus we may safely conclude, that every substance with which we are acquainted, will admit the rays of light, when made sufficiently thin.

Transparent colorless substances, whether solid or fluid, such as glass, water, or mica, reflect and transmit light of the same color; that is, the light seen through these bodies, and reflected from their surfaces, is white. This is true of all

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Why are not black, and white, considered as colors? Why is the color of grass green? How is the variety of colors accounted for, by considering all bodies transparent? What is said of the reflection of colored light by transparent substances?

transparent substances under ordinary circumstances; but if their thickness be diminished to a certain extent, these substances will both reflect, and transmit colored light of various hues, according to their thickness. Thus the thin plates of mica, which are left on the fingers, after handling that substance, will reflect prismatic rays of various colors.

There is a degree of tenuity, at which transparent substances cease to reflect any of the colored rays, but absorb, or transmit them all, in which case they become black. This may be proved by various experiments. If a soap bubble be closely observed, it will be seen that at first, the thickness is sufficient to reflect the prismatic rays from all its parts, but as it grows thinner, and just before it bursts, there may be seen a spot on its top, which turns black, thus transmitting all the rays at that part, and reflecting none. The same phenomenon is exhibited, when a film of air, or water, is pressed between two plates of glass. At the point of contact, or where the two plates press each other with the greatest force, there will be a black spot, while around this, there may be seen a system of colored rings.

From such experiments, Sir Isaac Newton concluded, that air, when below the thickness of *half a millionth of an inch*, ceases to reflect light; and also that water, when below the thickness of *three eighths of a millionth of an inch*, ceases to reflect light. But that both air and water, when their thickness is in a certain degree above these limits, reflect all the colored rays of the spectrum.

Now all solid bodies are more or less porous, having among their particles either void spaces, or spaces filled with some foreign matter, differing in density from the body itself, such as air or water. Even gold is not perfectly compact, since water can be forced through its pores. It is most probable, then, that the parts of the same body, differing in density, either reflect, or transmit the rays of light according to the size, or arrangement of their particles; and in proof of this, it is found that some bodies transmit the rays of one color, and reflect those of another. Thus the color which passes through a leaf of gold is green, while that which it reflects is yellow.

From a great variety of experiments on this subject, Sir

What substance is mentioned, as illustrating this fact? When is it said that transparent substances become black? How is it proved that fluids of extreme tenuity, absorb all the rays and reflect none?

Isaac Newton concludes that the transparent parts of bodies, according to the sizes of their transparent pores, reflect rays of one color, and transmit those of another, for the same reason that thin plates, or minute particles of air, water, and some other substances, reflect certain rays, and absorb, or transmit others, and that this is the cause of all their colors.

In confirmation of the truth of this theory, it may be observed, that many substances, otherwise opaque, become transparent, by filling their pores with some transparent fluid.

Thus the stone called *Hydrophane*, is perfectly opaque, when dry, but becomes transparent when dipped in water; and common writing paper becomes translucent, after it has absorbed a quantity of oil. The transparency, in these cases, may be accounted for, by the different refractive powers which the water and oil possess, from the stone, or paper, and in consequence of which the light is enabled to pass among their particles by refraction.

ASTRONOMY.

Astronomy is that science which treats of the motions and appearances of the heavenly bodies; accounts for the phenomena which these bodies exhibit to us, and explains the laws by which their motions, or apparent motions, are regulated.

Astronomy is divided into *Descriptive*, *Physical*, and *Practical.*

Descriptive astronomy demonstrates the magnitudes, distances, and densities of the heavenly bodies, and explains the phenomena dependant on their motions, such as the change of seasons, and the vicissitudes of day and night.

Physical astronomy explains the theory of planetary motion, and the laws by which this motion is regulated and sustained.

Practical astronomy details the description and use of astronomical instruments, and developes the nature and application of astronomical calculations.

The heavenly bodies are divided into three distinct classes,

What is the conclusion of Sir Isaac Newton, concerning the tenuity at which water and air cease to reflect light? What is said of the porous nature of solid bodies? What is astronomy? How is astronomy divided? What does descriptive astronomy teach? What is the object of physical astronomy? What is practical astronomy?

or systems, namely, the solar system, consisting of the sun, moon, and planets, the system of the fixed stars, and the system of the comets.

The Solar System.

The Solar system consists of the sun and twenty-nine other bodies, which revolve around him at various distances, and in various periods of time.

The bodies which revolve around the sun as a centre, are called *primary* planets. Thus, the Earth, Venus, and Mars, are primary planets. Those which revolve around the primary planets, are called *secondary* planets, *moons*, or *satellites*. Our moon is a secondary planet or satellite.

The primary planets revolve around the sun in the following order, and complete their revolutions in the following times, computed in our days and years. Beginning with that nearest to the sun, Mercury performs his revolution in 87 days and 23 hours; Venus, in 224 days, 17 hours; the Earth, attended by the moon, in 365 days, 6 hours; Mars, in 1 year, 322 days; Ceres, in 4 years, 7 months, and 10 days; Pallas, in 4 years, 7 months, and 10 days; Juno, in 4 years and 128 days; Vesta, in 3 years, 66 days, and 4 hours; Jupiter, in 11 years, 315 days, and 15 hours; Saturn, in 29 years, 161 days, and 19 hours; Herschel, in 83 years, 342 days, and 4 hours.

A year consists of the time which it takes a planet to perform one complete revolution through its orbit, or to pass once around the sun. Our earth performs this revolution in 365 days, and therefore this is the period of our year. Mercury completes her revolution in 88 days, and therefore her year is no longer than 88 of our days. But the planet Herschel is situated at such a distance from the sun, that his revolution is not completed in less than about 84 of our years. The other planets complete their revolutions in various periods of time, between these; so that the time of these periods is generally in proportion to the distance of each planet from the sun.

Ceres, Pallas, Juno, and Vesta, are the smallest of all the planets, and are called *Asteroids*.

How are the heavenly bodies divided? Of what does the solar system consist? What are the bodies called, which revolve around the sun as a centre? What are those called, which revolve around these primaries as a centre? In what order are the several planets situated, in respect to the sun? How long does it take each planet to make its revolution around the sun? What is a year? What planets are called asteroids?

Besides the above enumerated primary planets, our system contains eighteen secondary planets, or moons. Of these, our Earth has one moon, Jupiter four, Saturn seven, and Herschel six. None of these moons, except our own, and one or two of Saturn's, can be seen without a telescope. The seven other planets, so far as has been discovered, are entirely without moons.

All the planets move around the sun from east to west, and in the same direction do the moons revolve around their primaries, with the exception of those of Herschel, which appear to revolve in a contrary direction.

The paths in which the planets move round the sun, and in which the moons move round their primaries, are called their *orbits*. These orbits are not exactly circular, as they are commonly represented on paper, but are elliptical, or oval, so that all the planets are nearer the sun, when in one part of their orbits, than when in another.

In addition to their annual revolutions, some of the planets are known to have diurnal, or daily revolutions, like our earth. The periods of these daily revolutions have been ascertained in several of the planets by spots on their surfaces. But where no such mark is discernible, it cannot be ascertained whether the planet has a daily revolution or not, though this has been found to be the case in every instance where spots are seen, and, therefore, there is little doubt but all have a daily, as well as a yearly motion.

The *axis* of a planet is an imaginary line passing through its centre, and about which its diurnal revolution is performed. The *poles* of the planets are the extremities of this axis.

The orbits of Mercury and Venus are within that of the earth, and consequently they are called *inferior* planets. The orbits of all the other planets are without, or exterior to that of the earth, and these are called *superior* planets.

That the orbits of Mercury and Venus are within that of the earth, is evident from the circumstance, that they are never seen in opposition to the sun, that is, they never appear

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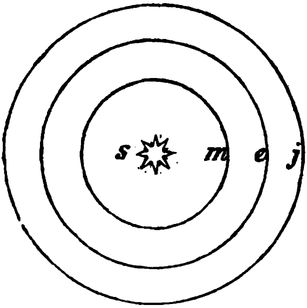
How many moons does our system contain? Which of the planets are attended by moons, and how many has each? In what direction do the planets move around the sun? What is the orbit of a planet? What revolutions have the planets, besides their yearly revolutions? Have all the planets diurnal revolutions? How is it known that the planets have daily revolutions? What is the axis of a planet? What is the pole of a planet? Which are the superior, and which the inferior planets?

in the west, when the sun is in the east. On the contrary, the orbits of all the other planets are proved to be outside of the earth's, since these planets are sometimes seen in opposition to the sun.

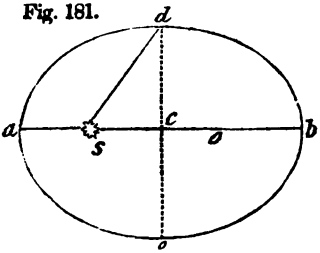
Fig. 180.



This will be understood by fig. 180, where suppose *s* to be the sun, *m* the orbit of Mercury or Venus, *e* the orbit of the earth, and *j* that of Jupiter. Now it is evident, that if a spectator be placed any where in the earth's orbit, as at *e*, he may sometimes see Jupiter in opposition to the sun, as at *j*, because then the spectator would be between Jupiter and the sun. But the orbit of Venus, being surrounded by that of the earth, she never can come in opposition to the sun, or in that part of the heavens opposite to him, as seen by us, because our earth never passes between her and the sun.

It has already been stated, that the orbits of the planets are elliptical, and that, consequently, these bodies are sometimes nearer the sun than at others. An ellipse, or oval, has two foci, and the sun, instead of being in the common centre, is always in the lower foci of their orbits.

Fig. 181.



The orbit of a planet is represented by fig. 181, where *a*, *d*, *b*, *e*, is an ellipse, with its two foci, *s* and *o*, the sun being in the focus *s*, which is called the lower focus.

When the earth, or any other planet, revolving around the sun, is in that part of its orbit nearest the

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How is it proved that the inferior planets are within the earth's orbit, and the superior ones without it? Explain fig. 180, and show why the inferior planets never can be in opposition to the sun. What are the shapes of the planetary orbits? What is meant by perihelion?

sun, as at *a*, it is said to be in its *perihelion;* and when in that part which is at the greatest distance from the sun, as at *b*, it is said to be in its *aphelion*. The line *s*, *d*, is the mean, or average distance of a planet's orbit from the sun.

Ecliptic.—The *planes* of the orbits of all the planets pass through the centre of the sun. The plane of an orbit is an imaginary surface, passing from one extremity or side of the orbit, to the other. If the rim of a drum head be considered the orbit, its plane would be the parchment extended across it, on which the drum is beaten.

Let us suppose the earth's orbit to be such a plane, cutting the sun through his centre, and extending out on every side to the starry heavens; the great circle so made, would mark the line of the *ecliptic*, or the sun's apparent path through the heavens.

This circle is called the sun's *apparent* path, because the revolution of the earth gives the sun the appearance of passing through it. It is called the ecliptic, because eclipses happen when the moon is in, or near, this apparent path.

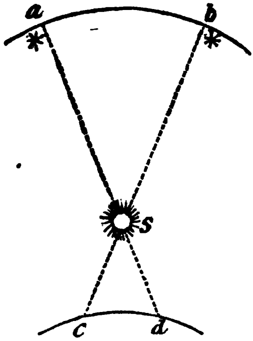
Zodiac.—The Zodiac is an imaginary belt, or broad circle, extending quite around the heavens. The ecliptic divides the zodiac into two equal parts, the zodiac extending 8 degrees on each side of the ecliptic, and therefore is 16 degrees wide. The zodiac is divided into 12 equal parts, called the *signs of the zodiac*.

The sun appears every year to pass around the great circle of the ecliptic, and consequently, through the 12 constellations, or signs of the zodiac. But it will be seen, in another place, that the sun, in respect to the earth, stands still, and that his apparent yearly course through the heavens is caused by the annual revolution of the earth around its orbit.

To understand the cause of this deception, let us suppose

What is the plane of an orbit? Explain what is meant by the ecliptic. Why is the ecliptic called the sun's apparent path? What is the zodiac? How does the ecliptic divide the zodiac? How far does the zodiac extend, on each side of the ecliptic?

Fig. 182.



that *s*, fig. 182, is the sun, *a b*, a part of the circle of the ecliptic, and *c d*, a part of the earth's orbit. Now, if a spectator be placed at *c*, he will see the sun in that part of the ecliptic marked by *b*, but when the earth moves in her annual revolution to *d*, the spectator will see the sun in that part of the heavens marked by *a*; so that the motion of the earth in one direction, will give the sun an apparent motion in the contrary direction.

A sign, or *constellation*, is a collection of fixed stars, and, as we have already seen, the sun appears to move through the twelve signs of the zodiac every year. Now the sun's place in the heavens, or zodiac, is found by his apparent conjunction, or nearness to any particular star in the constellation. Suppose a spectator at *c*, observes the sun to be nearly in a line with the star at *b*, then the sun would be near a particular star in a certain constellation. When the earth moves to *d*, the sun's place would assume another direction, and he would seem to have moved into another constellation, and near the star *a*.

Each of the 12 signs of the zodiac is divided into 30 smaller parts, called degrees; each degree into 60 equal parts, called minutes, and each minute into 60 parts, called seconds.

The division of the zodiac into signs, is of very ancient date, each sign having also received the name of some animal, or thing, which the constellation, forming that sign, was supposed to resemble. It is hardly necessary to say, that this is chiefly the result of imagination, since the figures made by the places of the stars, never mark the outlines of the figures of animals, or other things. This is, however, found to be the most convenient method of finding any particular star at this day, for among astronomers, any star, in each constellation, may be designated by describing the part of the animal in which it is

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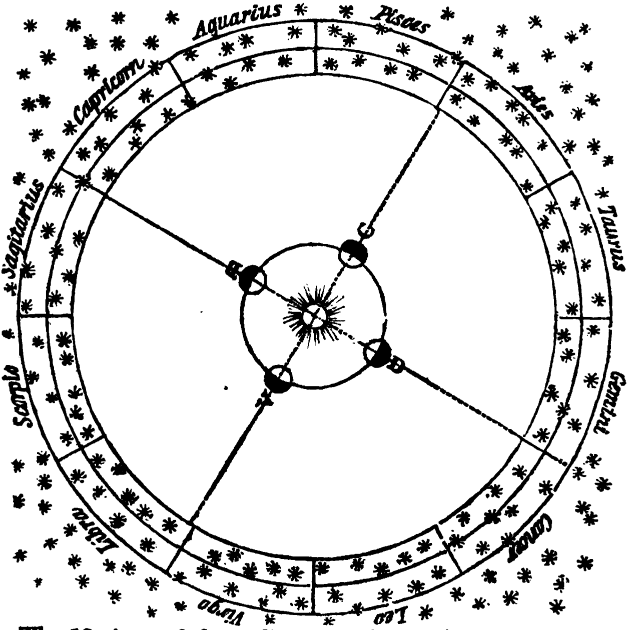
Explain fig. 182, and show why the sun seems to pass through the ecliptic, when the earth only revolves around the sun. What is a constellation, or sign? How is the sun's apparent place in the heavens found? Into how many parts are the signs of the zodiac divided, and what are these parts called?

situated. Thus, by knowing how many stars belong to the constellation Leo, or the Lion, we readily know what star is meant by that which is situated on the Lion's ear or tail.

The names of the 12 signs of the zodiac are, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricorn, Aquarius, and Pisces. The common names, or meaning of these words, in the same order, are, the Ram, the Bull, the Twins, the Crab, the Lion, the Virgin, the Scales, the Scorpion, the Archer, the Goat, the Waterer, and the Fishes.

Fig. 183.



The 12 signs of the zodiac, together with the sun, and the earth revolving around him, are represented at fig. 183. When the earth is at A, the sun will appear to be just entering the

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Is there any resemblance between the places of the stars, and the figures of the animals after which they are called? Explain why this is a convenient method of finding any particular star in a sign. What are the names of the 12 signs?

sign Aries, because then, when seen from the earth, he ranges towards certain stars at the beginning of that constellation. When the earth is at *C*, the sun will appear in the opposite part of the heavens, and therefore in the beginning of Libra. The middle line, dividing the circle of the zodiac into equal parts, is the line of the ecliptic.

Density of the Planets.—Astronomers have no means of ascertaining whether the planets are composed of the same kind of matter as our earth, or whether their surfaces are clothed with vegetables and forests, or not. They have, however, been able to ascertain the densities of several of them by observations on their mutual attraction. By density, is meant compactness, or the quantity of matter in a given space. When two bodies are of equal bulk, that which weighs most, has the greatest density. It was shown, while treating of the *properties of bodies*, that substances attract each other in proportion to the quantities of matter they contain. If, therefore, we know the dimensions of several bodies, and can ascertain the proportion in which they attract each other, their quantities of matter, or densities, are easily found.

Thus, when the planets pass each other in their circuits through the heavens, they are often drawn a little out of the lines of their orbits by mutual attraction. As bodies attract in proportion to their quantities of matter, it is obvious that the small planets, if of the same density, will suffer greater disturbance from this cause, than the large ones. But suppose two planets, of the same dimensions, pass each other, and it is found that one of them is attracted twice as far out of its orbit as the other, then, by the known laws of gravity, it would be inferred, that one of them contained twice the quantity of matter that the other did, and therefore that the density of the one was twice that of the other.

By calculations of this kind, it has been found, that the density of the sun is but a little greater than that of water, while Mercury is more than nine times as dense as water, having a specific gravity nearly equal to that of lead. The earth has a density about five times greater than that of the sun, and a little less than half that of Mercury. The densi-

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Explain why the sun will be in the beginning of Aries, when the earth is at *A*, fig. 184. How has the density of the planets been ascertained? What is meant by density? In what proportion do bodies attract each other? How are the densities of the planets ascertained? What is the density of the sun, of Mercury, and of the earth?

ties of the other planets seem to diminish in proportion as their distances from the sun increase, the density of Saturn, one of the most remote of planets, being only about one third that of water.

The Sun.

The sun is the centre of the solar system, and the great dispenser of heat and light to all the planets. Around the sun all the planets revolve, as around a common centre, he being the largest body in our system, and, so far as we know, the largest in the universe.

The distance of the sun from the earth is 95 millions of miles, and his diameter is estimated at 880,000 miles. Our globe, when compared with the magnitude of the sun, is a mere point, for his bulk is about *thirteen hundred thousand* times greater than that of the earth. Were the sun's centre placed in the centre of the moon's orbit, his circumference would reach two hundred thousand miles beyond her orbit in every direction, thus filling the whole space between us and the moon, and extending nearly as far beyond her as she is from us. A traveller, who should go at the rate of 90 miles a day, would perform a journey of nearly 33,000 miles in a year, and yet it would take such a traveller more than 80 years to go round the circumference of the sun. A body of such mighty dimensions, hanging on nothing, it is certain, must have emanated from an Almighty power.

The sun appears to move around the earth every 24 hours, rising in the east, and setting in the west. This motion, as will be proved in another place, is only apparent, and arises from the diurnal revolution of the earth.

The sun, although he does not, like the planets, revolve in an orbit, is, however, not without motion, having a revolution around his own axis, once in 25 days and 10 hours. Both the fact that he has such a motion, and the time in which it is performed, have been ascertained by the spots on his surface. If a spot is seen, on a revolving body, in a certain direction, it is obvious, that when the same spot is again seen, in the

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In what proportions do the densities of the planets appear to diminish? Where is the place of the sun, in the solar system? What is the distance of the sun from the earth? What is the diameter of the sun? Suppose the centre of the sun and that of the moon's orbit to be coincident, how far would the sun extend beyond the moon's orbit? How is it proved that the sun has a motion around his own axis? How often does the sun revolve?

same direction, that the body has made one revolution. By such spots the diurnal revolutions of the planets, as well as the sun, have been determined.

Spots on the sun seem first to have been observed in the year 1611, since which time they have constantly attracted attention, and have been the subject of investigation among astronomers. These spots change their appearance as the sun revolves on his axis, and become greater or less, to an observer on the earth, as they are turned to, or from him; they also change in respect to real magnitude and number: one spot, seen by Dr. Herschel, was estimated to be more than six times the size of our earth, being 50,000 miles in diameter. Sometimes forty or fifty spots may be seen at the same time, and sometimes only one. They are often so large as to be seen with the naked eye; this was the case in 1816.

In respect to the nature and design of these spots, almost every astronomer has formed a different theory. Some have supposed them to be solid opaque masses of scoriæ, floating in the liquid fire of the sun; others as satellites, revolving round him, and hiding his light from us; others as immense masses, which have fallen on his disc, and which are dark colored, because they have not yet become sufficiently heated. In two instances, these spots have been seen to burst into several parts, and the parts to fly in several directions, like a piece of ice thrown upon the ground. Others have supposed that these dark spots were the body of the sun, which became visible in consequence of openings through the fiery matter, with which he is surrounded. Dr. Herschel, from many observations with his great telescope, concludes, that the shining matter of the sun consists of a mass of phosphoric clouds, and that the spots on his surface are owing to disturbances in the equilibrium of this luminous matter, by which openings are made through it. There are, however, objections to this theory, as indeed there are to all the others, and at present it can only be said, that no satisfactory explanation of the cause of these spots has been given.

That the sun, at the same time that he is the great source of heat and light to all the solar worlds, may yet be capable of supporting animal life, has been the favourite doctrine of seve-

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When were spots of the sun first observed? What has been the difference in the number of spots observed? What was the size of the spot seen by Dr. Herschel? What has been advanced concerning the nature of these spots? Have they been accounted for satisfactorily?

ral able astronomers. Dr. Wilson first suggested that this might be the case, and Dr. Herschel, with his telescope, made observations which confirmed him in this opinion. The latter astronomer supposed that the functions of the sun, as the dispenser of light and heat, might be performed by a luminous, or phosphoric atmosphere, surrounding him at many hundred miles distance, while his solid nucleus might be fitted for the habitations of millions of reasonable beings. This doctrine is, however, rejected by most writers on the subject at the present day.

Mercury.

Mercury, the planet nearest the sun, is about 3000 miles in diameter, and revolves around him, at the distance of 37 millions of miles. The period of his annual revolution is 87 days, and he turns on his axis once in about 24 days.

The nearness of this planet to the sun, and the short time his fully illuminated disc is turned towards the earth, has prevented astronomers from making many observations on him.

No signs of an atmosphere have been observed in this planet. The sun's heat at Mercury is about seven times greater than it is on the earth, so that water, if nature follows the same laws there that she does here, cannot exist at Mercury, except in the state of steam.

The nearness of this planet to the sun, prevents his being often seen. He may, however, sometimes be observed just before the rising, and a little after the setting of the sun. When seen after sunset, he appears a brilliant, twinkling star, showing a white light, which, however, is much obscured by the glare of twilight. When seen in the morning, before the rising of the sun, his light is also obscured by the sun's rays.

Mercury sometimes crosses the disc of the sun or comes between the earth and that luminary, so as to appear like a small dark spot passing over the sun's face. This is called the *transit* of Mercury.

Venus.

***Venus* is the other planet, whose orbit is within that of the**

What is said concerning the sun's being a habitable globe? What is the diameter of Mercury, and what are his periods of annual and diurnal revolution? How great is the sun's heat at Mercury? At what times is Mercury to be seen? What is a transit of Mercury?

earth. Her diameter is about 8600 miles, being somewhat larger than the earth.

Her revolution around the sun is performed in 224 days, at the distance of 68 millions of miles from him. She turns on her axis once in 23 hours, so that her day is a little shorter than ours.

Venus, as seen from the earth, is the most brilliant of all the primary planets, and is better known than any nocturnal luminary except the moon. When seen through a telescope, she exhibits the phases, or horned appearance of the moon, and her face is sometimes variegated with dark spots. Venus may often be seen in the day time, even when she is in the vicinity of the blazing light of the sun. A luminous appearance around this planet, seen at certain times, proves that she has an atmosphere. Some of her mountains are several times more elevated than any on our globe, being from 10 to 22 miles high. Venus sometimes makes a transit across the sun's disc, in the same manner as Mercury, already described. The transits of Venus occur only at distant periods from each other. The last transit was in 1769, and the next will not happen until 1874. These transits have been observed by astronomers with the greatest care and accuracy, since it is by observations on them that the true distances of the earth and planets from the sun are determined.

When Venus is in that part of her orbit which gives her the appearance of being west of the sun, she rises before him, and is then called the *morning* star; and when she appears east of the sun, she is behind him in her course, and is then called the *evening* star. These periods do not agree, either with the yearly revolution of the earth, or of Venus, for she is alternately 290 days the morning star, and 290 days the evening star. The reason of this is, that the earth and Venus move round the sun in the same direction, and hence her relative motion, in respect to the earth, is much slower than her absolute motion in her orbit. If the earth had no yearly motion, Venus would be the morning star one half of the year, and the evening star the other half.

Where is the orbit of Venus, in respect to that of the earth? What is the time of Venus' revolution round the sun? How often does she turn on her axis? What is said of the height of the mountains in Venus? On what account are the transits of Venus observed with great care? When is Venus the morning, and when the evening star? How long is Venus the morning, and how long the evening star?

The Earth.

The next planet in our system, nearest the sun, is the Earth. Her diameter is 7912 miles. This planet revolves around him in 365 days, 5 hours, and 48 minutes; and at the distance of 95 millions of miles. It turns round its own axis once in 24 hours, making a day and a night. The Earth's revolution round the sun is called its *annual*, or *yearly* motion, because it is performed in a year; while the revolution around its own axis, is called the *diurnal*, or daily motion, because it takes place every day. The figure of the earth, with the phenomena connected with her motion, will be explained in another place.

The Moon.

The Moon, next to the sun, is, to us, the most brilliant and interesting of all the celestial bodies. Being the nearest to us of any of the heavenly orbs, and apparently designed for our use, she has been observed with great attention, and many of the phenomena which she presents, are therefore better understood and explained, than those of the other planets.

While the earth revolves round the sun in a year, it is attended by the Moon, which makes a revolution round the earth once in 27 days 7 hours and 43 minutes. The distance of the Moon from the earth is 240,000 miles, and her diameter about 2000 miles.

Her surface, when seen through a telescope, appears diversified with hills, mountains, valleys, rocks, and plains, presenting a most interesting and curious aspect: but the explanation of these phenomena are reserved for another section.

Mars.

The next planet in the solar system, is Mars, his orbit surrounding that of the earth. The diameter of this planet is upwards of 4000 miles, being about half that of the earth. The revolution of Mars around the sun is performed in nearly 687 days, or in somewhat less than two of our years, and he turns on his axis once in 24 hours and 40 minutes. His mean

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How long does it take the earth to revolve round the sun? What is meant by the earth's annual revolution, and what by her diurnal revolution? Why are the phenomena of the moon better explained than those of the other planets? In what time is a revolution of the moon about the earth performed? What is the distance of the moon from the earth? What is the diameter of Mars? How much longer is a year at Mars than our year?

distance from the sun is 144 millions of miles, so that he moves in his orbit at the rate of about 55,000 miles in an hour. The days and nights, at this planet, and the different seasons of the year, bear a considerable resemblance to those of the earth. The density of Mars is less than that of the earth, being only three times that of water.

Mars reflects a dull red light, by which he may be distinguished from the other planets. His appearance through the telescope, is remarkable for the great number and variety of spots which his surface presents.

Mars has an atmosphere of great density and extent, as is proved by the dim appearance of the fixed stars, when seen through it. When any of the stars are seen nearly in a line with this planet, they give a faint, obscure light, and the nearer they approach the line of his disc, the fainter is their light, until the star is entirely obscured from the sight.

This planet sometimes appears much larger to us than at others, and this is readily accounted for by his greater or less distance. At his nearest approach to the earth, his distance is only 50 millions of miles, while his greatest distance is 240 millions of miles; making a difference in his distance of 190 millions of miles, or the diameter of the earth's orbit.

The sun's heat at this planet is less than half that which we enjoy.

To the inhabitants of Mars, our planet appears alternately as the morning and evening star, as Venus does to us.

Vesta, Juno, Pallas, and Ceres.

These planets were unknown until recently, and are therefore sometimes called the *new* planets. It has been mentioned, that they are also called *Asteroids*.

The orbit of *Vesta* is next in the solar system to that of Mars. This planet was discovered by Dr. Olbers, of Bremen, in 1807. The light of Vesta is of a pure white, and in a clear night she may be seen with the naked eye, appearing about the size of a star of the 5th or 6th magnitude. Her revolution round the sun is performed in 3 years and 66 days, at the distance of 223 millions of miles from him.

What is his rate of motion in his orbit? What is his appearance through the telescope? How is it proved that Mars has an atmosphere of great density? Why does Mars sometimes appear to us larger than at others? How great is the sun's heat at Mars? Which are the new planets, or asteroids? When was Vesta discovered? What is the period of Vesta's annual revolution?

Juno was discovered by Mr. Harding, of Bremen, in 1804 Her mean distance from the sun is 253 millions of miles Her orbit is more elliptical than that of any other planet, and in consequence, she is sometimes 127 millions of miles nearer the sun than at others. This planet completes its annual revolution in 4 years and about 4 months, and revolves round its axis in 27 hours. Its diameter is 1400 miles.

Pallas was also discovered by Dr. Olbers, in 1802. Its distance from the sun is 226 millions of miles, and its periodic revolution round him, is performed in 4 years and 7 months.

Ceres was discovered in 1801, by Piazzi, of Palermo. This planet performs her revolution in the same time as Pallas, being 4 years and 7 months. Her distance from the sun 260 millions of miles. According to Dr. Herschel, this planet is only about 160 miles in diameter.

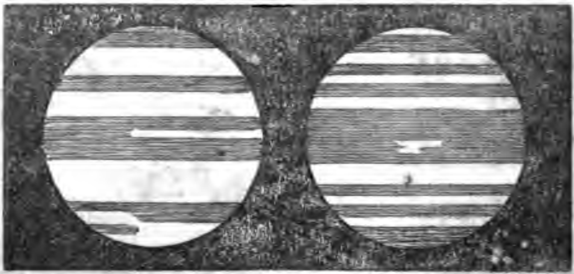
Jupiter.

Jupiter is 89,000 miles in diameter, and performs his annual revolution once in about 11 years, at the distance of 490 millions of miles from the sun. This is the largest planet in the solar system, being about 1400 times larger than the earth. His diurnal revolution is performed in nine hours and fifty-five minutes, giving his surface at the equator, a motion of 28,000 miles per hour. This motion is about twenty times more rapid than that of our earth at the equator.

Jupiter, next to Venus, is the most brilliant of the planets, though the light and heat of the sun on him is nearly 25 times less than on the earth.

This planet is distinguished from all the others, by an appearance resembling bands, which extend across his disc,

Fig. 184.

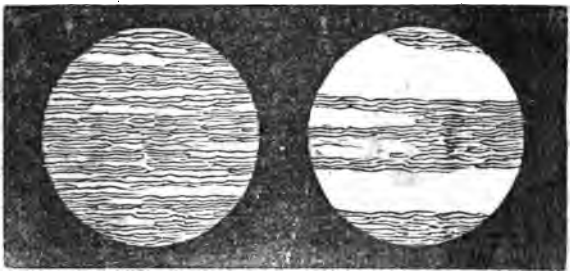


When was Juno discovered? What is her distance from the sun? What is the period of her revolution, and what her diameter?

These are termed *belts*, and are variable, both in respect to number and appearance. Sometimes seven or eight are seen, several of which extend quite across his face, while others appear broken, or interrupted.

These bands, or belts, when the planet is observed through a telescope, appear as represented in fig. 184. This appearance is much the most common, the belts running quite across the face of the planet in parallel lines. Sometimes, however, his aspect is quite different from this, for in 1780, Dr. Herschel saw the whole disc of Jupiter covered with small curved lines, each of which appeared broken, or interrupted, the whole having a parallel direction across his disc, as in fig. 185.

Fig. 185.



Different opinions have been advanced by astronomers respecting the cause of these appearances. By some, they have been regarded as clouds, or as openings in the atmosphere of the planet, while others imagine that they are the marks of great natural changes, or revolutions, which are perpetually agitating the surface of that planet. It is, however, most probable, that these appearances are produced by the agency of some cause, of which we, on this little earth, must always be entirely ignorant.

Jupiter has four satellites, or moons, two of which are sometimes seen with the naked eye. They move round, and

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What is said of Pallas and Ceres? What is the diameter of Jupiter? What is his distance from the sun? What is the period of Jupiter's diurnal revolution? What is the sun's heat and light at Jupiter, when compared with that of the earth? For what is Jupiter particularly distinguished? Is the appearance of Jupiter's belts always the same, or do they change? What is said of the cause of Jupiter's belted appearance? How many moons has Jupiter, and what are the periods of their revolutions?

attend him in his yearly revolution, as the moon does our earth. They complete their revolutions at different periods, the shortest of which is less than ten days, and the longest seventeen days.

These satellites often fall into the shadow of their primary, in consequence of which they are eclipsed, as seen from the earth. The eclipses of Jupiter's moons have been observed with great care by astronomers, because they have been the means of determining the exact longitude of places, and the velocity with which light moves through space. How longitude is determined by these eclipses, cannot be explained or understood at this place, but the method by which they become the means of ascertaining the velocity of light, may be readily comprehended. An eclipse of one of these satellites, appears, by calculation, to take place sixteen minutes sooner, when the earth is in that part of her orbit nearest to Jupiter, than it does when the earth is in that part of her orbit at the greatest distance from him. Hence light is found to be sixteen minutes in crossing the earth's orbit, and as the sun is in the centre of this orbit, or nearly so, it must take about 8 minutes for the light to come from him to us. Light, therefore, passes at the velocity of 95 millions of miles, our distance from the sun, in about 8 minutes, which is nearly 200 thousand miles in a second.

Saturn.

The planet Saturn revolves round the sun in a period of about 30 of our years, and at the distance from him, of 900 millions of miles. His diameter is 79,000 miles, making his bulk nearly nine hundred times greater than that of the earth, but notwithstanding this vast size, he revolves on his axis once in about ten hours. Saturn therefore performs upwards of 25,000 diurnal revolutions in one of his years, and hence his year consists of more than 25,000 days; a period of time equal to more than 10,000 of our days. On account of the remote distance of Saturn from the sun, he receives only about a 90th part of the heat and light which we enjoy on the earth. But to compensate, in some degree, for this vast distance from the sun, Saturn has seven moons, which revolve

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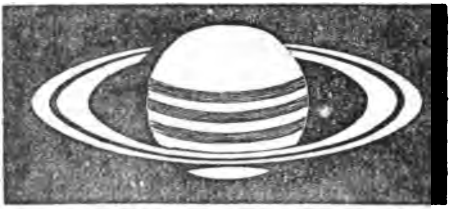
What occasions the eclipses of Jupiter's moons? Of what use are these eclipses to astronomers? How is the velocity of light ascertained by the eclipses of Jupiter's satellites? What is the time of Saturn's periodic revolution round the sun? What is his distance from the sun? What his diameter? What is the period of his diurnal revolution? How many days make a year at Saturn?

round him at different distances, and at various periods, from 1 to 80 days.

Saturn is distinguished from the other planets by his *ring*, as Jupiter is by his belt. When this planet is viewed through a telescope, he appears surrounded by an immense luminous circle, which is represented by fig. 186.

Fig. 186.



There are indeed two luminous circles, or rings, one within the other, with a dark space between them, so that they do not appear to touch each other. Neither does the inner ring touch the body of the planet, there being, by estimation, about the distance of 30,000 miles between them. The external circumference of the outer ring is 640,000 miles, and its breadth from the outer to the inner circumference, 7,200 miles, or nearly the diameter of our earth. The dark space, between the two rings, or the interval between the inner, and outer ring, is 2800 miles.

This immense appendage revolves round the sun with the planet,—performs daily revolutions with it, and according to Dr. Herschel, is a solid substance, equal in density to the body of the planet itself.

The design of Saturn's ring, an appendage so vast, and so different from any thing presented by the other planets, has always been a matter of speculation and inquiry among astronomers. One of its most obvious uses appears to be that of reflecting the light of the sun on the body of the planet, and possibly it may reflect the heat also, so as in some degree to soften the rigour of so inhospitable a climate.

As this planet revolves around the sun, one of its sides is illuminated during one half of the year, and the other side during the other half; so that, as Saturn's year is equal to thirty of our years, one of his sides will be enlightened and darkened, alternately, every fifteen years, as the poles of our earth are alternately in the light and dark every year.

How many moons has Saturn? How is Saturn particularly distinguished from all the other planets? What distance is there between the body of Saturn and his inner ring? What distance is there between his inner and outer ring? What is the circumference of the outer ring?

Fig. 187.

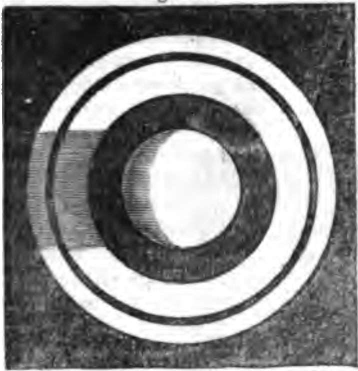


Fig. 187 represents Saturn as seen by an eye placed at right angles to the plane of his ring. When seen from the earth, his position is always oblique, as represented by fig. 186.

The inner white circle, represents the body of the planet, enlightened by the sun. The dark circle next to this, is the unenlightened space between the body of the planet and the inner ring, being the dark expanse of the heavens beyond the planet. The two white circles are the rings of the planet, with the dark space between them, which also is the dark expanse of the heavens.

Herschel.

In consequence of some inequalities in the motions of Jupiter and Saturn, in their orbits, several astronomers had suspected that there existed another planet beyond the orbit of Saturn, by whose attractive influence these irregularities were produced. This conjecture was confirmed by Dr. Herschel, in 1781, who in that year discovered the planet, which is now generally known by the name of its discoverer, though called by him *Georgium sidus*. The orbit of Herschel is beyond that of Saturn, and at the distance of 1800 millions of miles from the sun. To the naked eye this planet appears like a star of the sixth magnitude, being, with the exception of some of the comets, the most remote body, so far as is known, in the solar system.

Herschel completes his revolution round the sun in nearly 84 of our years, moving in his orbit at the rate of 15,000 miles in an hour. His diameter is 35,000 miles, so that his bulk is about eighty times that of the earth. The light and heat of

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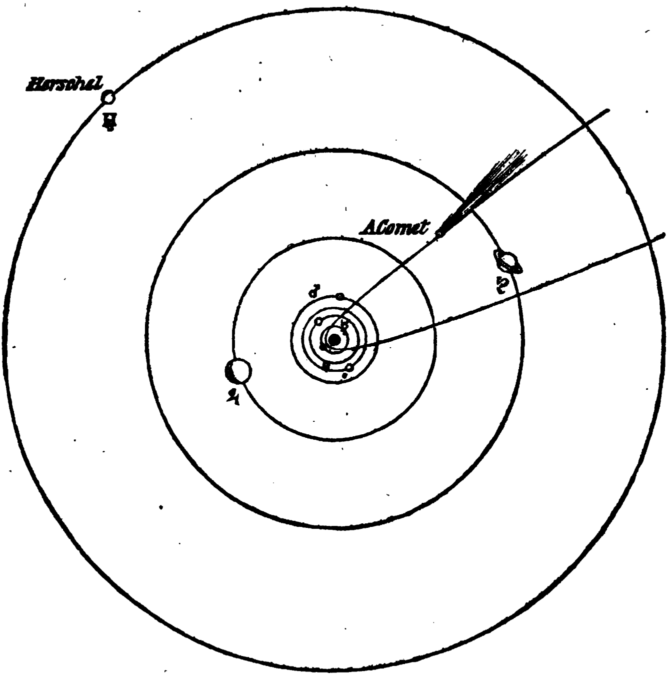
How long is one of Saturn's sides alternately in the light and dark? In what position is Saturn represented by fig. 187? What circumstance led to the discovery of Herschel? In what year, and by whom, was Herschel discovered? What is the distance of Herschel from the sun? In what period is his revolution round the sun performed? What is the diameter of Herschel?

the sun at Herschel is about 360 times less than it is at the earth, and yet it has been found by calculation, that this light is equal to 248 of our full moons, a striking proof of the inconceivable quantity of light emitted by the sun.

This planet has six satellites, which revolve round him at various distances, and in different times. The periods of some of these have been ascertained, while those of the others remain unknown.

Fig. 188.



Having now given a short account of each planet composing the solar system, the relative situation of their several orbits, with the exception of those of the Asteroids, are shown by fig. 189.

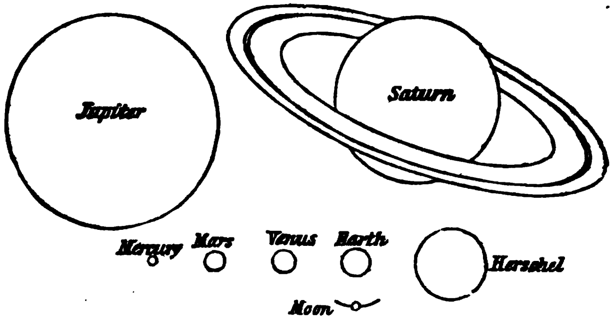
In the figure, the orbits are marked by the signs of each

What is the quantity of light and heat at Herschel, when compared with that of the earth?

planet, of which the first, or that nearest the sun, is Mercury, the next Venus, the third the Earth, the fourth Mars; then come those of the Asteroids, then Jupiter, then Saturn, and lastly Herschel.

The comparative dimensions of the planets are delineated at fig. 189.

Fig. 189.



Motions of the Planets.

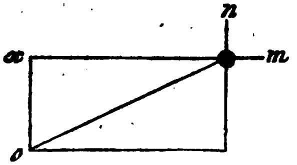
It is said that when Sir Isaac Newton was near demonstrating the great truth, that gravity is the cause which keeps the heavenly bodies in their orbits, he became so agitated with the thoughts of the magnitude and consequences of his discovery, as to be unable to proceed with his demonstrations, and desired a friend to finish what the intensity of his feelings would not allow him to complete.

We have seen, in a former part of this work, that all undisturbed motion is straight forward, and that a body projected into open space, would continue, perpetually, to move in a right line, unless retarded or drawn out of this course by some external cause.

To account for the motions of the planets in their orbits, we will suppose that the earth, at the time of its creation, was thrown by the hand of the Creator into open space, the sun having been before created and fixed in his present place.

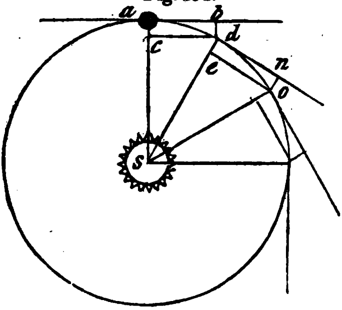
Under *Compound Motion*, it has been shown, that when a body is acted on by two forces perpendicular to each other, its motion will be in a diagonal line between the direction of the two forces.

Fig. 190.



But we will again here suppose that a ball be moving in the line *m x*, fig. 190, with a given force, and that another force half as great should strike it in the direction of *n*, the ball would then describe the diagonal of a parallelogram, whose length would be just equal to twice its breadth, and the line of the ball would be straight, because it would obey the impulse and direction of these two forces only.

Fig. 191.



Now let *a*, fig. 191, represent the earth, and *S* the sun; and suppose the earth to be moving forward, in the line from *a* to *b*, and to have arrived at *a*, with a velocity sufficient, in a given time, and without disturbance, to have carried it to *b*. But at the point *a*, the sun *S* acts upon the earth with his attractive power, and with a force which would draw it to *c*, in the same space of time that it would otherwise have gone to *b*. Then the earth, instead of passing to *b*, in a straight line, would be drawn down to *d*, the diagonal of the parallelogram *a*, *b*, *d*, *c*. The line of direction, in fig. 190, is straight, because the body moved obeys only the direction of the two forces, but it is curved from *a* to *d*, fig. 191, in consequence of the continued force of the sun's attraction, which produces a constant deviation from a right line.

When the earth arrives at *d*, still retaining its projectile or centrifugal force, its line of direction would be towards *n*, but while it would pass along to *n* without disturbance, the attracting force of the sun is again sufficient to bring it to *e*,

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Suppose a body to be acted on by two forces perpendicular to each other, in what direction will it move? Why does the ball, fig. 190, move in a straight line? Why does the earth, fig. 191, move in a curved line? Explain fig. 191, and show how the two forces act to produce a circular line of motion.

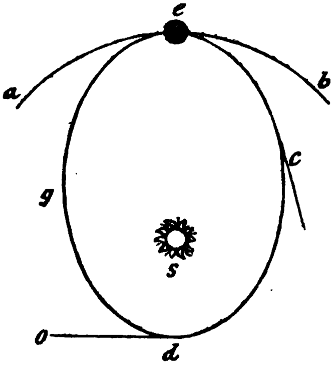
in a straight line, so that, in obedience to the two impulses, it again describes the curve to *o*.

It must be remembered, in order to account for the circular motions of the planets, that the attractive force of the sun is not exerted at once, or by a single impulse, as is the case with the cross forces, producing a straight line, but that this force is imparted by degrees, and is constant. It therefore acts equally on the earth, in all parts of the course from *a* to *d*, and from *d* to *o*. From *o*, the earth having the same impulses as before, it moves in the same curved or circular direction, and thus its motion is continued perpetually.

The tendency of the earth to move forward in a straight line, is called the *centrifugal force*, and the attraction of the sun, by which it is drawn downwards, or towards a centre, is called its *centripetal force*, and it is by these two forces that the planets are made to perform their constant revolutions around the sun.

In the above explanation, it has been supposed that the sun's attraction, which constitutes the earth's gravity, was at all times equal, or that the earth was at an equal distance from the sun, in all parts of its orbit. But, as heretofore explained, the orbits of all the planets are elliptical, the sun being placed in the lower focus of the eclipse. The sun's attraction is, therefore, stronger in some parts of their orbits than in others, and for this reason their velocities are greater at some periods of their revolutions than at others.

Fig. 192.



To make this understood, suppose, as before, that the centrifugal and centripetal forces so balance each other, that the earth moves round the circular orbit *a e b*, fig. 192,

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What is the projectile force of the earth called? What is the attractive force of the sun, which draws the earth towards him, called? Explain fig. 192, and show the reason why the velocity is increased from *c* to *d*, and why it is not retarded from *d* to *g*.

until it comes to the point *e*; and at this point, let us suppose, that the gravitating force is too strong for the force of projection, so that the earth, instead of continuing its former direction towards *b*, is attracted by the sun *s*, in the curve *e c*. When at *c*, the line of the earth's projectile force, instead of tending to carry it farther from the sun, as would be the case, were it revolving in a circular orbit, now tends to draw it still nearer to him, so that at this point, it is impelled by both forces towards the sun. From *c*, therefore, the force of gravity increasing in proportion as the square of the distance between the sun and earth diminishes, the velocity of the earth will be uniformly accelerated, until it arrives at the point nearest the sun, *d*. At this part of its orbit, the earth will have gained, by its increased velocity, so much centrifugal force, as to give it a tendency to overcome the sun's attraction, and to fly off in the line *d o*. But the sun's attraction being also increased by the near approach of the earth, the earth is retained in its orbit, notwithstanding its increased centrifugal force, and it therefore passes through the opposite part of its orbit, from *d* to *g*, at the same distance from him that it approached. As the earth passes from the sun, the force of gravity tends continually to retard its motion, as it did to increase it while approaching him. But the velocity it had acquired in approaching the sun, gives it the same rate of motion from *d* to *g*, that it had from *c* to *d*. From *g*, the earth's motion is uniformly retarded, until it again arrives at *e*, the point from which it commenced, and from whence it describes the same orbit, by virtue of the same forces, as before.

The earth, therefore, in its journey round the sun, moves at very unequal velocities, sometimes being retarded, and then again accelerated by the sun's attraction.

It is an interesting circumstance, respecting the motions of the planets, that if the contents of their orbits be divided into unequal triangles, the acute angles of which centre at the sun, with the line of the orbit for their bases, the centre of the planet will pass through each of these bases in equal times.

This will be understood by fig. 193, the elliptical circle being supposed to be the earth's orbit, with the sun *s*, in one of the foci.

Now the spaces 1, 2, 3, &c. though of different shapes, are of the same dimensions, or contain the same quantity of sur

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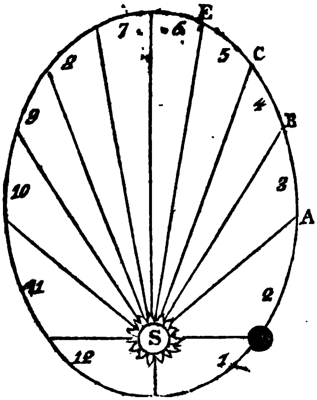
What is meant by a planet's passing through equal spaces in equal times?

Fig. 193.



face. The earth, we have already seen, in its journey round the sun, describes an ellipse, and moves more rapidly in one part of its orbit than in another. But whatever may be its actual velocity, its comparative motion is through equal areas in equal times. Thus its centre passes from E to C, and from C to A, in the same period of time, and so of all the other divisions marked in the figure. If the figure, therefore, be considered the plane of the earth's orbit, divided in 12 equal areas, answering to the 12 months of the year, the earth will pass through the same areas in every month, but the spaces through which it passes will be increased, during every month, for one half the year, and diminished, during every month, for the other half.

The reason why the planets, when they approach near the sun, do not fall to him, in consequence of his increased attraction, and why they do not fly off into open space, when they recede to the greatest distance from him, may be thus explained.

Taking the earth as an example, we have shown, that when in the part of her orbit nearest the sun, her velocity is greatly increased by his attraction, and that consequently the earth's centrifugal force is increased in proportion. As an illustration of this, we know that a thread which will sustain an ounce ball when whirled round in the air, at the rate of 50 revolutions in a minute, would be broken, were these revolutions increased to the number of 60 or 70 in a minute, and that the ball would then fly off in a straight line. This shows that when the motion of a revolving body is increased, its cen-

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How is it shown, that if the motion of a revolving body is increased, its projectile force is also increased? By what force is the earth's velocity increased, as it approaches the sun? When the earth is nearest the sun, why does it not fall to him? When the earth's centrifugal force is greatest, what prevents its flying to the sun?

trifugal force is also increased. Now, the velocity of the earth increases in an inverse proportion, as its distance from the sun diminishes, and in proportion to the increase of velocity is its centrifugal force increased; so that, in any other part of its orbit, except when nearest the sun, this increase of velocity would carry the earth away from its centre of attraction. But this increase of the earth's velocity is caused by its near approach to the sun, and consequently the sun's attraction is increased, as well as the earth's velocity. In other terms, when the centrifugal force is increased, the centripetal force is increased in proportion, and thus while the centrifugal force prevents the earth from falling to the sun, the centripetal force prevents it from moving off in a straight line.

When the earth is in that part of its orbit most distant from the sun, its projectile velocity being retarded by the counter force of the sun's attraction, becomes greatly diminished, and then the centripetal force becomes stronger than the centrifugal, and the earth is again brought back by the sun's attraction, as before, and in this manner its motion goes on without ceasing. It is supposed, as the planets move through spaces void of resistance, that their centrifugal forces remain the same as when they first emanated from the hand of the Creator, and that this force, without the influence of the sun's attraction, would carry them forward into infinite space.

The Earth.

It is almost universally believed, at the present day, that the apparent daily motion of the heavenly bodies from east to west, is caused by the real motion of the earth from west to east, and yet there are comparatively few who have examined the evidence on which this belief is founded. For this reason, we will here state the most obvious, and to a common observer, the most convincing proofs of the earth's revolution. These are, first, the inconceivable velocity of the heavenly bodies, and particularly the fixed stars around the earth, if she stands still. Second, the fact, that all astronomers of the present age agree that every phenomenon which the heavens present, can be best accounted for, by supposing the earth to revolve. Third, the analogy to be drawn from many of the other planets, which are known to revolve on their axes; and fourth, the different lengths of days and nights at the different

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What are the most obvious and convincing proofs that the earth revolves on its axis?

planets, for did the sun revolve about the solar system, the days and nights at many of the planets must be of similar lengths.

The distance of the sun from the earth being 95 millions of miles, the diameter of the earth's orbit is twice its distance from the sun, and, therefore, 190 millions of miles. Now, the diameter of the earth's orbit, when seen from the nearest fixed star, is a mere point, and were the orbit a solid mass of opaque matter, it could not be seen, with such eyes as ours, from such a distance. This is known by the fact, that these stars appear no larger to us, even when our sight is assisted by the best telescopes, when the earth is in that part of her orbit nearest them, than when at the greatest distance, or in the opposite part of her orbit. The approach, therefore, of 190 millions of miles towards the fixed stars, is so small a part of their whole distance from us, that it makes no perceptible difference in their appearance. Now, if the earth does not turn on her axis once in 24 hours, these fixed stars must revolve around the earth at this amazing distance once in 24 hours. If the sun passes around the earth in 24 hours, he must travel at the rate of nearly 400,000 miles in a minute; but the fixed stars are at least 400,000 times as far beyond the sun, as the sun is from us, and, therefore, if they revolve around the earth, must go at the rate of 400,000 times 400,000 miles, that is, at the rate of 160,000,000,000, or 160 billions of miles in a minute; a velocity of which we can have no more conception than of infinity or eternity.

In respect to the analogy to be drawn from the known revolutions of the other planets, and the different lengths of days and nights among them, it is sufficient to state, that to the inhabitants of Jupiter, the heavens appear to make a revolution in about 10 hours, while to those of Venus, they appear to revolve once in 23 hours, and to the inhabitants of the other planets a similar difference seems to take place, depending on the periods of their diurnal revolutions. Now, there is no more reason to suppose that the heavens revolve

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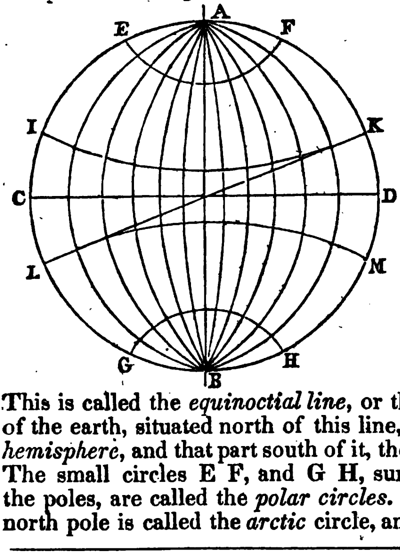
Were the earth's orbit a solid mass, could it be seen by us, at the distance of the fixed stars? Suppose the earth stood still, how fast must the sun move to go round it in 24 hours? At what rate must the fixed stars move to go round the earth in 24 hours? If the heavens appear to revolve every 10 hours at Jupiter, and every 24 hours at the earth, how can this difference be accounted for, if they revolve at all? Is there any more reason to believe that the sun revolves round the earth, than round any of the other planets?

round us, than there is to suppose that they revolve around any of the other planets, since the same apparent revolution is common to them all, and as we know that the other planets, at least many of them, turn on their axes, and as all the phenomena presented by the earth, can be accounted for by such a revolution, it is folly to conclude otherwise.

Circles and Divisions of the Earth.

It will be necessary for the pupil to retain in his memory the names and directions of the following lines, or circles, by which the earth is divided into parts. These lines, it must be understood, are entirely imaginary, there being no such divisions marked by nature on the earth's surface. They are, however, so necessary, that no accurate description of the earth, or of its position with respect to the heavenly bodies, can be conveyed without them.

Fig. 194.



The earth, whose diameter is 7912 miles, is represented by the globe, or sphere, fig. 194. The straight line passing thro' its centre, and about which it turns, is called its *axis*, and the two extremities of the axis are the *poles* of the earth, A being the north pole, and B the south pole. The line C D, crossing the axis, passes quite round the earth, and divides it into two equal parts. This is called the *equinoctial line*, or the *equator*. That part of the earth, situated north of this line, is called the *northern hemisphere*, and that part south of it, the *southern hemisphere*. The small circles E F, and G H, surrounding or including the poles, are called the *polar circles*. That surrounding the north pole is called the *arctic* circle, and that surrounding the

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How can all the phenomena of the heavens be accounted for, if they do not revolve? What is the axis of the earth? What are the poles of the earth? What is the equator? Where are the northern and southern hemisphere? What are the polar circles?

south, the *antartic circle*. Between these circles, there is, on each side of the equator another circle, which marks the extent of the tropics towards the north and south, from the equator. That to the north of the equator, I K, is called the *tropic of Cancer*, and that to the south, L M, the *tropic of Capricorn*. The circle L K, extending obliquely across the two tropics, and crossing the axis of the earth, and the equator at their point of intersection, is called the *ecliptic*. This circle, as already explained, belongs rather to the heavens than the earth, being an imaginary extension of the plane of the earth's orbit in every direction towards the stars. The line in the figure, shows the comparative position or direction of the ecliptic in respect to the equator, and the axis of the earth.

The lines crossing those already described, and meeting at the poles of the earth, are called *meridian lines*, or mid-day lines, for when the sun is on the meridian of a place, it is the middle of the day at that place, and as these lines extend from north to south, the sun shines on the whole length of each, at the same time, so that it is 12 o'clock, at the same time, on every place situated on the same meridian.

The spaces on the earth, between the lines extending from east to west, are called *zones*. That which lies between the tropics, from M to K, and from I to L, is called the *torrid zone*, because it comprehends the hottest portion of the earth. The spaces which extend from the tropics, north and south, to the polar circles, are called *temperate zones*, because the climates are temperate, and neither scorched with the heat, like the tropics, nor chilled with the cold, like the frigid zones. That lying north of the tropic of Cancer, is called the *north temperate zone*, and that south of the tropic of Capricorn, the *south temperate zone*. The spaces included within the polar circles, are called the *frigid zones*. The lines which divide the globe into two equal parts, are called the *great circles;* these are the ecliptic and the equator. Those dividing the earth into smaller parts are called the *lesser circles*; these are the lines dividing the tropics from the temperate zones, and the temperate zones from the frigid zones, &c.

Which is the arctic, and which the antarctic circle? Where is the tropic of Cancer, and where the tropic of Capricorn? What is the ecliptic? What are the meridian lines? On what part of the earth is the torrid zone? How are the north and south temperate zones bounded? Where are the frigid zones? Which are the great, and which the lesser circles of the earth?

The ecliptic, we have already seen, is divided into 360 equal parts, called degrees. All circles, however large or small, are divided into degrees, minutes, and seconds, in the same manner as the ecliptic.

The horizon is distinguished into the *sensible* and *rational*. The sensible horizon is that portion of the surface of the earth which bounds our vision, or the circle around us, where the sky seems to meet the earth. When the sun rises, he appears above the sensible horizon, and when he sets, he sinks below it. The rational horizon is an imaginary line passing through the centre of the earth, and dividing it into two equal parts.

The *axis* of the ecliptic is an imaginary line passing through its centre and perpendicular to its plane. The extremities of this perpendicular line, are called the *poles* of the ecliptic.

If the ecliptic, or great plane of the earth's orbit, be considered on the horizon, or parallel with it, and the line of the earth's axis be inclined to the axis of this plane, or the axis of the ecliptic, at an angle of 23½ degrees, it will represent the relative positions of the orbit, and the axis of the earth. These positions are, however, merely relative, for if the position of the earth's axis be represented perpendicular to the equator, as A B, fig. 194, then the ecliptic will cross this plane obliquely, as in that figure. But when the earth's orbit is considered as having no inclination, its axis, of course, will have an inclination, to the axis of the ecliptic, of 23½ degrees.

As the orbits of all the other planets are inclined to the ecliptic, perhaps it is the most natural and convenient method to consider this as a horizontal plane, with the equator inclined to it, instead of considering the equator on the plane of the horizon, as is sometimes done.

The inclination of the earth's axis to the axis of its orbit never varies, but always makes an angle with it of 23½ degrees, as it moves round the sun. The axis of the earth is therefore always parallel with itself. That is, if a line be drawn through the centre of the earth, in the direction of its axis, and extended north and south, beyond the earth's diame-

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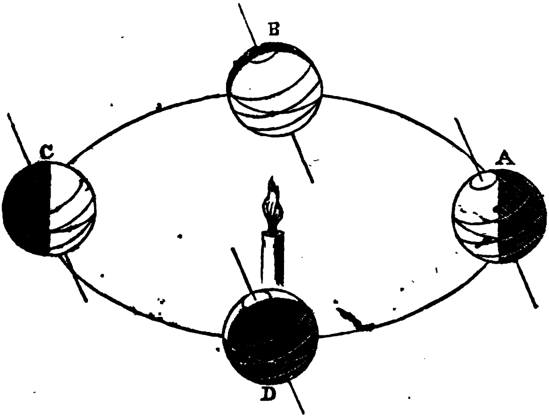
How are circles divided? How is the sensible horizon distinguished from the rational? What is the axis of the ecliptic? What are the poles of the ecliptic? How many degrees is the axis of the earth inclined to that of the ecliptic? What is said concerning the relative positions of the earth's axis and the plane of the ecliptic? Are the orbits of the other planets parallel to the earth's orbit, or inclined to it? What is meant by the earth's axis being parallel to itself?

ter, the line so produced will always be parallel to the same line, or any number of lines, so drawn, when the earth is in different parts of its orbit.

Suppose a rod to be fixed into the flat surface of a table, and so inclined as to make an angle with a perpendicular from the table of 23½ degrees. Let this rod represent the axis of the earth, and the surface of the table, the ecliptic. Now place on the table a lamp, and round the lamp hold a wire circle three or four feet in diameter, so that it shall be parallel with the plane of the table, and as high above it as the flame of the lamp. Having prepared a small terrestrial globe, by passing a wire through it for an axis, and letting it project a few inches each way, for the poles, take hold of the north pole, and carry it round the circle, with the poles constantly parallel to the rod rising above the table. The rod being inclined 23½ degrees from a perpendicular, the poles and axis will be inclined in the same degree, and thus the axis of the earth will be inclined to that of the ecliptic every where in the same degree, and lines drawn in the direction of the earth's axis will be parallel to each other in any part of its orbit.

Fig. 195.



This will be understood by fig. 195, where it will be seen,

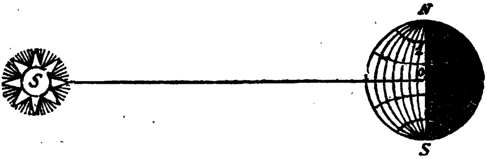
How does it appear by fig. 195, that the axis of the earth is parallel to itself, in all parts of its orbit? How are the annual and diurnal revolutions of the earth illustrated by fig. 195?

that the poles of the earth, in the several positions of A, B, C, and D, being equally inclined, are parallel to each other. Supposing the lamp to represent the sun, and the wire circle the earth's orbit, the actual position of the earth, during its annual revolution around the sun, will be comprehended: and if the globe be turned on its axis, while passing round the lamp, the diurnal or daily revolution of the earth will also be represented.

Day and Night.

Were the direction of the earth's axis perpendicular to the plane of its orbit, the days and nights would be of equal length all the year, for then just one half of the earth, from pole to pole, would be enlightened, and at the same time the other half would be in darkness.

Fig. 196.



Suppose the line *s o*, fig. 196, from the sun to the earth, to be the plane of the earth's orbit, and that *n s*, is the axis of the earth perpendicular to it, then it is obvious, that exactly the same points on the earth would constantly pass through the alternate vicissitudes of day and night; for all who live on the meridian line between *n* and *s*, which line crosses the equator at *o*, would see the sun at the same time, and consequently, as the earth revolves, would pass into the dark hemisphere at the same time. Hence in all parts of the globe, the days and nights would be of equal length, at any given place.

Now it is the inclination of the earth's axis, as above described, which causes the lengths of the days and nights to differ at the same place at different seasons of the year, for on reviewing the position of the globe at A, fig. 195, it will be observed, that the line formed by the enlightened and dark

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Explain, by fig. 196, why the days and nights would every where be equal, were the axis of the earth perpendicular to the plane of his orbit. What is the cause of the unequal lengths of the days and nights in different parts of the world?

hemispheres, does not coincide with the line of the axis and poles, as in fig. 196, but that the line formed by the darkness and the light, extends obliquely across the line of the earth's axis, so that the north pole is in the light, while the south is in the dark. In the position A, therefore, an observer at the north pole would see the sun constantly, while another at the south pole, would not see it at all. Hence those living in the north temperate zone, at the season of the year when the earth is at A, or in the summer, would have long days and short nights, in proportion as they approached the polar circle; while those who live in the south temperate zone, at the same time, and when it would be winter there, would have long nights and short days in the same proportion.

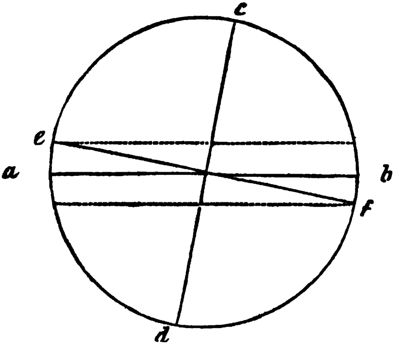
Seasons of the year.

The vicissitudes of the seasons are caused by the annual revolution of the earth around the sun, together with the inclination of its axis to the plane of its orbit.

It has already been explained, that the ecliptic is the plane of the earth's orbit, and is supposed to be placed on a level with the earth's horizon, and hence, that this plane is considered the standard, by which the inclination of the lines crossing the earth, and the obliquity of the orbits of the other planets, are to be estimated.

The equinoctial line, or the great circle passing round the middle of the earth, is inclined to the ecliptic, as well as the line of the earth's axis, and hence in passing round the sun, the equinoctial line intersects, or crosses the ecliptic, in two places, opposite to each other.

Fig. 197.



Suppose *a b*, fig. 197, to be the ecliptic, *e f*, the equator, and *c d*, the earth's axis. The ecliptic and equator are supposed to be seen edgewise, so as to appear like lines

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What are the causes which produce the seasons of the year? In what position is the equator, with respect to the ecliptic?

instead of circles. Now it will be understood by the figure that the inclination of the equator to the ecliptic, (or the sun's apparent annual path through the heavens,) will cause these lines, namely, the line of the equator and the line of the ecliptic, to cut, or cross each other, as the sun makes his apparent annual revolution, and that this intercession will happen twice in the year, when the earth is in the two opposite points of her orbit.

These periods are on the 21st of March, and the 21st of September, in each year, and the points at which the sun is seen at these times, are called the *equinoctial* points. That which happens in September is called the *autumnal* equinox, and that which happens in March, the *vernal* equinox. At these seasons, the sun rises at 6 o'clock and sets at 6 o'clock, and the days and nights are equal in length in every part of the globe.

The *solstices* are the points where the ecliptic and the equator are at the greatest distance from each other. The earth, in its yearly revolution, passes through each of these points. One is called the *summer*, and the other the *winter* solstice. The sun is said to enter the summer solstice on the 21st of June; and at this time, in our hemisphere, the days are longest, and the nights shortest. On the 21st of December he enters his winter solstice, when the length of the days and nights are reversed from what they were in June before, the days being shortest and the nights longest.

Having learned these explanations, the student will be able to understand in what order the seasons succeed each other, and the reason why such changes are the effect of the earth's revolution.

Suppose the earth, fig. 198, to be in her summer solstice, which takes place on the 21st of June. At this period she will be at *a*, having her north pole, *n*, so inclined towards the sun, that the whole arctic circle will be illuminated, and consequently the sun's rays will extend 23½ degrees, the breadth of the polar circles, beyond the north pole. The diurnal revo-

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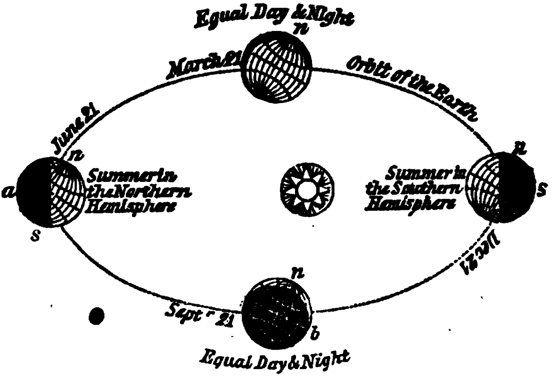
At what times in the year do the line of the ecliptic and that of the equinox intersect each other? What are these points of intersection called? Which is the autumnal and which the vernal equinox? At what time does the sun rise and set, when he is in the equinoxes? What are the solstices? When the sun enters the summer solstice, what is said of the length of the days and nights? When does the sun enter the winter solstice, and what is the proportion between the length of the day and nights?

Fig. 198.



lution, therefore, when the earth is at *a*, causes no succession of day and night at the pole, since the whole frigid zone is within reach of his rays. The people who live within the arctic circle, will consequently, at this time, enjoy perpetual day. During this period, just the same proportion of the earth that is enlightened in the northern hemisphere, will be in total darkness in the opposite region of the southern hemisphere; so that while the people of the north are blessed with perpetual day, those of the south are groping in perpetual night. Those who live near the arctic circle in the north temperate zone, will, during the winter, come, for a few hours, within the region of night, by the earth's diurnal revolution; and the greater the distance from the circle, the longer will be their nights, and the shorter their days. Hence, at this season, the days will be longer than the nights every where between the equator and the arctic circle. At the equator, the days and nights will be equal, and between the equator and the south polar circle, the nights will be longer than the days, in the same proportion as the days are longer than the nights, from the equator to the arctic circle.

At what season of the year is the whole arctic circle illuminated? At what season is the whole antarctic circle in the dark? While the people near the north pole enjoy perpetual day, what is the situation of those near the south pole? At what season will the days be longer than the nights every where between the equator and the arctic circle? At what season will the nights be longer than the days in the southern hemisphere?

As the earth moves round the sun, the line which divides the darkness, and the light, gradually approaches the poles, till having performed one quarter of her yearly journey from the point *a*, she comes to *b*, about the 21st of September. At this time, the boundary of light and darkness passes through the poles, dividing the earth equally from north to south; and thus in every part of the world the days and nights are of equal length, the sun being 12 hours alternately above and below the horizon. In this position of the earth, the sun is said to be in the *autumnal equinox.*

In the progress of the earth from *b* to *c*, the light of the sun gradually reaches a little more of the antartic circle. The days, therefore, in the northern hemisphere, grow shorter at every diurnal revolution, until the 21st of December, when the whole arctic circle is involved in total darkness. And now, the same places which enjoyed constant day in the June before, are involved in perpetual night. At this time, the sun, to those who live in the northern hemisphere, is said to be in his *winter solstice;* and then the winter nights are just as long as were the summer days, and the winter days as long as the summer nights.

When the earth has gone another quarter of her annual journey, and has come to the point of her orbit opposite to where she was on the 21st of September, which happens on the 21st of March, the line dividing the light from the darkness again passes through both poles. In this position of the earth with respect to the sun, the days and nights are again equal all over the world, and the sun is said to be in his *vernal* equinox.

From the vernal equinox, as the earth advances, the northern hemisphere enjoys more and more light, while the southern falls into the region of darkness, in proportion, so that the days north of the equator increase in length, until the 21st of June, at which time, the sun is again longest above the horizon, and the shortest time below it.

Thus the apparent motion of the sun, from east to west, is caused by the real motion of the earth from west to east. If

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When will the days and nights be equal in all parts of the earth? At what season of the year is the whole arctic circle involved in darkness? When are the days and nights equal all over the world? When is the sun in the vernal equinox? What is the cause of the apparent motion of the sun from east to west? What is the apparent path of the sun, but the real path of the earth?

the earth is in any point of its orbit, the sun will always seem in the opposite point in the heavens. When the earth moves one degree to the west, the sun seems to move the same distance to the east; and when the earth has completed one revolution in its orbit, the sun appears to have completed a revolution through the heavens. Hence, it follows, that the ecliptic, or the apparent path of the sun through the heavens, is the real path of the earth round the sun.

It will be observed by a careful perusal of the above explanation of the seasons, and a close inspection of the figure by which it is illustrated, that the sun constantly shines on a portion of the earth equal to 90 degrees north, and 90 degrees south from his place in the heavens, and consequently, that he always enlightens 180 degrees, or one half of the earth. If, therefore, the axis of the earth were perpendicular to the plane of its orbit, the days and nights would every where be equal, for as the earth performs its diurnal revolutions, there would be 12 hours day, and 12 hours night. But since the inclination of its axis is 23½ degrees, the light of the sun is thrown 23½ degrees beyond the north pole; that is, it enlightens the earth 23½ degrees further in that direction, when the north pole is turned towards the sun, than it would, had the earth's axis no inclination. Now, as the sun's light reaches only 90 degrees north or south of his place in the heavens, so when the arctic circle is enlightened, the antartic circle must be in the dark; for if the light reaches 23½ degrees beyond the north pole, it must fall 23½ degrees short of the south pole.

As the earth travels round the sun, in his yearly circuit, this inclination of the poles is alternately towards, and from him. During our winter, the north polar region is thrown beyond the rays of the sun, while a corresponding portion around the south pole enjoys the sun's light. And thus at the poles there are alternately six months of darkness and winter, and six months of sunshine and summer. While we, in the northern hemisphere, are chilled by the cold blasts of winter, the inhabitants of the southern hemisphere are enjoying all the delights of summer; and while we are scorched

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Had the earth's axis no inclination, why would the days and nights always be equal? How many degrees does the sun's light reach, north and south of him, on the earth? During our winter, is the north pole turned to, or from the sun? At the poles, how many days and nights are there in the year? When it is winter in the northern hemisphere, what is the season in the southern hemisphere?

by the rays of a vertical sun in June and July, our southern neighbors are shivering with the rigors of mid-winter.

At the equator, no such changes take place. The rays of the sun, as the earth passes around him, are vertical twice a year at every place between the tropics. Hence, at the equator, there are two summers and no winter, and as the sun there constantly shines on the same half of the earth in succession, the days and nights are always equal, there being 12 hours of light, and 12 of darkness.

Motion of the Earth.—The motion of the earth round the sun, is at the rate of 68,000 miles in an hour, while its motion on its own axis, at the equator, is at the rate of about 1042 miles in the hour. The equator, being that part of the earth most distant from its axis, the motion there is more rapid than towards the poles, in proportion to its greater distance from the axis of motion. See fig. 16.

The method of ascertaining the velocity of the earth's motion, both in its orbit and round its axis, is simple, and easily understood; for by knowing the diameter of the earth's orbit, its circumference is readily found, and as we know how long it takes the earth to perform her yearly circuit, we have only to calculate what part of her journey she goes through in an hour. By the same principle, the hourly rotation of the earth is as readily ascertained.

We are insensible to these motions, because not only the earth but the atmosphere, and all terrestrial things, partake of the same motion, and there is no change in the relation of objects in consequence of it. If we look out at the window of a steam-boat, when it is in motion, the boat will seem to stand still, while the trees and rocks on the shore appear to pass rapidly by us. This deception arises from our not having any object with which to compare this motion, when shut up in the boat; for then every object around us keeps the same relative position. And so, in respect to the motion of the earth, having nothing with which to compare its movement, except the heavenly bodies, when the earth moves in one direction, these objects appear to move in the contrary direction.

Causes of the Heat and Cold of the Seasons.

We have seen that the earth revolves round the sun in an

At what rate does the earth move around the sun? How fast does it move around its axis at the equator? How is the velocity of the earth ascertained? Why are we insensible of the earth's motion?

elliptical orbit, of which the sun is one of the foci, and consequently, that the earth is nearest him, in one part of her orbit than in another. From the great difference we experience between the heat of summer and that of winter, we should be led to suppose that the earth must be much nearer the sun in the hot season, than in the cold. But when we come to inquire into this subject, and to ascertain the distance of the sun at different seasons of the year, we find that the great source of heat and light is nearest us during the cold of winter, and at the greatest distance during the heat of summer.

It has been explained, under the article *Optics*, that the angle of vision depends on the distance at which a body of given dimensions is seen. Now, on measuring the angular dimension of the sun, with accurate instruments, at different seasons of the year, it has been found that his dimensions increase and diminish, and that these variations correspond exactly with the supposition, that the earth moves in an elliptical orbit. If, for instance, his apparent diameter be taken in March, and then again in July, it will be found to have diminished, which diminution is only to be accounted for, by supposing that he is at a greater distance from the observer in July than in March. From July, his angular diameter gradually increases, till January, when it again diminishes, and continues to diminish, until July. By many observations, it is found, that the greatest apparent diameter of the sun, and therefore his least distance from us, is in January, and his least diameter, and therefore his greatest distance, is in July. The actual difference is about three millions of miles, the sun being that distance further from the earth in July than in January. This, however, is only about one sixtieth of his mean distance from us, and the difference we should experience in his heat, in consequence of this difference of distance, will therefore be very small. Perhaps the effect of his proximity to the earth may diminish, in some small degree, the severity of winter.

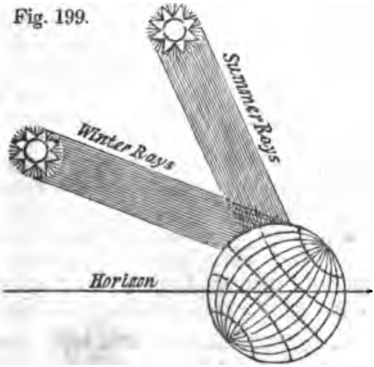
The heat of summer, and the cold of winter, must therefore

At what season of the year is the sun at the greatest, and at what season the least distance, from the earth? How is it ascertained that the earth moves in an elliptical orbit, by the appearance of the sun? When does the sun appear under the greatest apparent diameter, and when under the least? How much farther is the sun from us in July, than in January? What effect does this difference produce on the earth? How is the heat of summer, and the cold of winter, accounted for?

arise from the difference in the meridian altitude of the sun, and in the time of his continuance above the horizon. In summer, the solar rays fall on the earth, in nearly a perpendicular direction, and his powerful heat is then constantly accumulated by the long days and short nights of the season. In winter, on the contrary, the solar rays fall so obliquely on the earth, as to produce little warmth, and the small effect they do produce during the short days of that season, is almost entirely destroyed by the long nights which succeed. The difference between the effects of perpendicular and oblique rays, seems to depend, in a great measure, on the different extent of surface over which they are spread. When the rays of the sun are made to pass through a convex lens, the heat is increased, because the number of rays which naturally covered a large surface, are then made to cover a smaller one, so that the power of the glass depends on the number of rays thus brought to a focus. If, on the contrary, the rays of the sun are suffered to pass through a concave lens, their natural heating power is diminished, because they are dispersed, or spread over a wider surface than before.

Now, to apply these different effects to the summer and winter rays of the sun, let us suppose that the rays falling perpendicularly on a given extent of surface, impart to it a certain degree of heat, then it is obvious, that if the same number of rays be spread over twice that extent of surface, their heating power would be diminished in proportion, and that only half the heat would be imparted. This is the effect produced by the sun's rays in the winter. They fall so obliquely on the earth, as to occupy nearly double the space that the same number of rays do in the summer.

Fig. 199.



Why do the perpendicular rays of summer produce greater effects than the oblique rays of winter? How is this illustrated by the convex and concave lenses? How is the actual difference of the summer and winter rays shown?

This is illustrated by fig. 199, where the number of rays both in winter and summer, are supposed to be the same. But it will be observed, that the winter rays, owing to their oblique direction, are spread over nearly twice as much surface as those of summer.

It may, however, be remarked, that the hottest season is not usually at the exact time of the year, when the sun is most vertical, and the days the longest, as is the case towards the end of June, but some time afterwards, as in July and August.

To account for this, it must be remembered, that when the sun is nearly vertical, the earth accumulates more heat by day than it gives out at night, and that this accumulation continues to increase after the days begin to shorten, and consequently, the greatest elevation of temperature is some time after the longest days. For the same reason, the thermometer generally indicates the greatest degree of heat at two or three o'clock on each day, and not at 12 o'clock, when the sun's rays are most powerful.

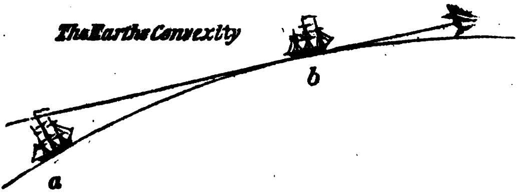
Figure of the Earth.

Astronomers have proved that all the planets, together with their satellites, have the shape of the sphere or globe, and hence, by analogy, there was every reason to suppose, that the earth would be found of the same shape; and several phenomena tend to prove, beyond all doubt, that this is its form. The figure of the earth is not, however, exactly that of a globe, or ball, because its diameter is about 34 miles less from pole to pole, than it is at the equator. But that its general figure is that of a sphere, or ball, is proved by many circumstances.

When one is at sea, or standing on the sea shore, the first part of a ship seen at a distance, is its mast. As the vessel advances, the mast rises higher and higher above the horizon, and finally the hull, and whole ship, become visible. Now, were the earth's surface an exact plane, no such appearance would take place, for we should then see the hull long before the mast or rigging, because it is much the largest object.

Why is not the hottest season of the year at the period when the days are longest, and the sun most vertical? What is the general figure of the earth? How much less is the diameter of the earth at the poles than at the equator? How is the convexity of the earth proved, by the approach of a ship at sea?

Fig 200



It will be plain by fig. 200, that were the ship, *a*, elevated, so that the hull should be on a horizontal line with the eye, the whole ship would be visible instead of the topmast, there being no reason, except the convexity of the earth, why the whole ship should not be visible at *a*, as well as at *b*.

We know, for the same reason, that in passing over a hill, the tops of the trees are seen, before we can discover the ground on which they stand; and that when a man approaches from the opposite side of a hill, his head is seen before his feet.

It is a well known fact also, that navigators have set out from a particular port, and by sailing continually westward, have passed around the earth, and again reached the port from which they sailed. This could never happen, were the earth an extended plain, since then the longer the navigator sailed in one direction, the further he would be from home.

Another proof of the spheroidal form of the earth, is the figure of its shadow on the moon, during eclipses, which shadow is always bounded by a circular line.

These circumstances prove beyond all doubt, that the form of the earth is globular, but that it is not an exact sphere; and that it is depressed or flattened at the poles, is shown by the difference in the lengths of pendulums vibrating seconds at the poles and at the equator.

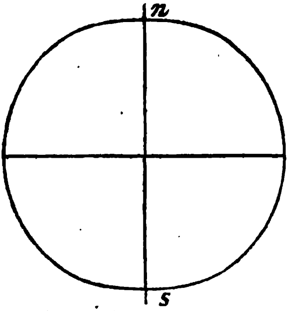
Under the article *pendulum*, it was shown that its vibrations depend on the attraction of gravitation, and that as the centre of the earth is the centre of this attraction, so the nearer this instrument is carried to that point, the stronger will be the attraction, and consequently the more frequent its vibrations.

From a great number of experiments, it has been found

Explain fig. 200. What other proofs of the globular shape of the earth are mentioned? How is it proved by the vibrations of the pendulum, that the earth is flattened at the poles?

that a pendulum, which vibrates seconds at the equator, has its number of vibrations increased, when it is carried towards the poles, and as its number of vibrations depends upon its length, a clock which keeps accurate time at the equator, must have its pendulum lengthened at the poles. And so, on the contrary, a clock going correctly at, or near the poles, must have its pendulum shortened, to keep exact time at the equator. Hence the force of gravity is greatest at the poles, and least at the equator.

Fig. 201.



The manner in which the figure of the earth differs from that of a sphere, is represented by fig. 201, where *n* is the north pole, and *s* the south pole, the line from one of these points to the other, being the axis of the earth, and the line crossing this the equator. It will be seen by this figure that the surface of the earth, at the poles, is nearer its centre, than the surface at the equator. The actual difference between the polar and equatorial diameters is in the proportion of 300 to 301. The earth is therefore called an *oblate spheroid*, the word oblate signifying the reverse of oblong, or shorter in one direction than in another.

The compression of the earth at the poles, and the consequent accumulation of matter at the equator, is probably the effect of its diurnal revolution, while it was in a soft or plastic state. If a ball of soft clay, or putty, be made to revolve rapidly, by means of a stick passed through its centre, as an axis, it will swell out in the middle, or equator, and be depressed at the poles, assuming the precise figure of the earth. This figure is the natural and obvious consequence of the centrifugal force, which operates to throw the matter off, in proportion to its distance from the axis of motion, and the rapidity with which the ball is made to revolve. The parts about the equator would therefore tend to fly off, and leave

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In what proportion is the polar, less than the equatorial diameter? What is the earth called, in reference to this figure? How is it supposed that it came to have this form? How is the form of the earth illustrated by experiment? Explain the reason why a plastic ball will swell at the equator, when made to revolve.

the other parts, in consequence of the centrifugal force, while those about the poles, being near the centre of motion, would receive a much smaller impulse. Consequently the ball would swell, or bulge out at the equator, which would produce a corresponding depression at the poles.

The weight of a body at the poles is found to be greater than at the equator, not only because the poles are nearer the centre of the earth than the equator, but because the centrifugal force there tends to lessen its gravity. The wheels of machines, which revolve with the greatest rapidity, are made in the strongest manner, otherwise they will fly in pieces, the centrifugal force not only overcoming the gravity, but the cohesion of their parts.

It has been found, by calculation, that if the earth turned over once in 84 minutes and 43 seconds, the centrifugal force at the equator would be equal to the power of gravity there, and that bodies would entirely lose their weight. If the earth revolved more rapidly than this, all the buildings, rocks, mountains, and men, at the equator, would not only lose their weight, but would fly away, and leave the earth.

Solar and Siderial Time.

The stars appear to go round the earth in 23 hours, 56 minutes, and 4 seconds, while the sun appears to perform the same revolution in 24 hours, so that the stars gain 3 minutes and 56 seconds upon the sun every day. In a year, this amounts to a day, or to the time taken by the earth to perform one diurnal revolution. It therefore happens, that when time is measured by the stars, there are 366 days in the year, or 366 diurnal revolutions of the earth, while, if measured by the sun from one meridian to another, there are only 365 whole days in the year. The former are called the *siderial*, and the latter *solar* days.

To account for this difference, we must remember that the earth, while she performs her daily revolutions, is constantly advancing in her orbit, and that, therefore, at 12 o'clock today, she is not precisely at the same place in respect to the

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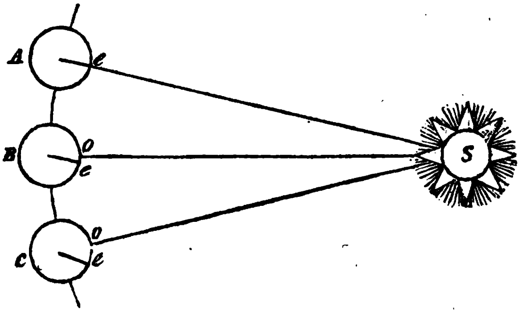
What two causes render the weights of bodies less at the equator than at the poles? What would be the consequence on the weights of bodies at the equator, did the earth turn over once in 84 minutes and 43 seconds? The stars appear to move round the earth in less time than the sun, what does the difference amount to in a year? What is the year measured by a star called? What is that measured by the sun called?

sun, that she was at 12 o'clock yesterday, or will be to-morrow. But the fixed stars are at such an amazing distance from us, that the earth's orbit, in respect to them, is but a point; and therefore, as the earth's diurnal motion is perfectly uniform, she revolves from any given star to the same star again, in exactly the same period of absolute time. The orbit of the earth, were it a solid mass, instead of an imaginary circle, would have no appreciable length or breadth, when seen from a fixed star, and therefore, whether the earth performed her diurnal revolutions at a particular station, or while passing round in her orbit, would make no appreciable difference with respect to the star. Hence the same star, at every complete daily revolution of the earth, appears precisely in the same direction at all seasons of the year. The moon, for instance, would appear at exactly the same point, to a person who walks round a circle of a hundred yards in diameter, and for the same reason a star appears in the same direction from all parts of the earth's orbit, though 190 millions of miles in diameter.

If the earth had only a diurnal motion, her revolution, in respect to the sun, would coincide exactly with the same revolution in respect to the stars; but while she is making one revolution on her axis towards the east, she advances in the same direction about one degree in her orbit, so that to bring the same meridian towards the sun, she must make a little more than one entire revolution.

Fig. 202



How is the difference in time between the solar and siderial year accounted for? The earth's orbit is but a point, in reference to a star; how is this illustrated?

To make this plain, suppose the sun, *s*, fig. 202, to be exactly on a meridian line marked at *e*, on the earth *A*, on a given day. On the next day, the earth, instead of being at *A*, as on the day before, advances in its orbit to *B*, and in the mean time having completed her revolution, in respect to a star, the same meridian line is not brought under the sun, as on the day before, but falls short of it as at *e*, so that the earth has to perform more than a revolution, by the distance from *e* to *o*, in order to bring the same meridian again under the sun. So on the next day, when the earth is at *C*, she must again complete more than two revolutions, since leaving *A*, by the space from *e* to *o*, before it will again be noon at *e*.

Thus, it is obvious, that the earth must complete one revolution, and a portion of a second revolution, equal to the space she has advanced in her orbit, in order to bring the same meridian back again to the sun. This small portion of a second revolution amounts daily to the 365th part of her circumference, and therefore, at the end of the year, to one entire rotation, and hence in 365 days, the earth actually turns on her axis 366 times. Thus, as one complete rotation forms a siderial day, there must, in the year, be one siderial, more than there are solar days, one rotation of the earth, with respect to the sun, being lost, by the earth's yearly revolution. The same loss of a day happens to a traveller, who, in passing round the earth towards the west, reckons his time by the rising and setting of the sun. If he passes round towards the east, he will gain a day for the same reason.

Equation of Time.

As the motion of the earth about its axis is perfectly uniform, the siderial days, as we have already seen, are exactly of the same length, in all parts of the year. But as the orbit of the earth, or the apparent path of the sun, is inclined to the earth's axis, and as the earth moves with different velocities in different parts of its orbit, the solar, or natural days, are sometimes greater and sometimes less than 24 hours, as shown

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Had the earth only a diurnal revolution, would the siderial and solar time agree? Show by fig. 202, how siderial, differs from solar time. Why does not the earth turn the same meridian to the sun at the same time every day? How many times does the earth turn on her axis in a year? Why does she turn more times than there are days in the year? Why are the solar days sometimes greater, and sometimes less than 24 hours?

by an accurate clock. The consequence is, that a true sun dial, or noon mark, and a true time piece, agree with each other, only a few times in a year. The difference between the sun dial and clock, thus shown, is called the *equation of time.*

The difference between the sun and a well regulated clock, thus arises from two causes, the inclination of the earth's axis to the ecliptic, and the elliptical form of the earth's orbit.

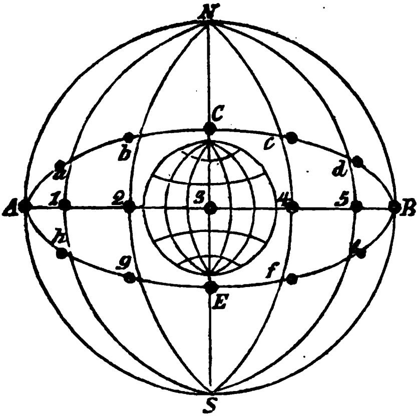
That the earth moves in an ellipse, and that its motion is more rapid sometimes than at others, as well as that the earth's axis is inclined to the ecliptic, have already been explained and illustrated. It remains, therefore, to show how these two combined causes, the elliptical form of the orbit, and the inclination of the axis, produce the disagreement between the sun and clock. In this explanation, we must consider the sun as moving around the ecliptic, while the earth revolves on her axis.

Equal, or *mean* time, is that which is reckoned by a clock, supposed to indicate exactly 24 hours, from 12 o'clock on one day, to 12 o'clock on the next day. *Apparent* time, is that which is measured by the apparent motion of the sun in the heavens, as indicated by a meridian line, or sun dial.

Were the earth's orbit a perfect circle, fig. 196, and her axis perpendicular to the plane of this orbit, the days would be of uniform length, and there would be no difference between the clock and the sun; both would indicate 12 o'clock at the same time, on every day in the year. But on account of the inclination of the earth's axis to the ecliptic, unequal portions of the sun's apparent path through the heavens will pass any meridian in equal times. This may be readily explained to the pupil, by means of an artificial globe, but perhaps it will be understood by the following diagram.

What is the difference between the time of a sun dial and a clock called? What are the causes of the difference between the sun and clock? In explaining equation of time, what motion is considered as belonging to the sun, and what motion to the earth? What is equal, or mean time? What is apparent time?

Fig. 203.



Let *A N B S*, fig. 203, be the concave of the heavens, in the centre of which is the earth. Let the line A B, be the equator, extending through the earth and the heavens, and let A, *a*, *b*, C, *c*, and *d*, be the ecliptic, or the apparent path of the sun through the heavens. Also, let A, 1, 2, 3, 4, 5, be equal distances on the equator, and A, *a*, *b*, C, *c*, and *d*, equal portions of the ecliptic, corresponding with A 1, 2, 3, 4, and 5. Now we will suppose, that there are two suns, namely, a false, and a real one; that the false one passes through the celestial equator, which is only an extension of the earth's equator to the heavens; while the real sun has an apparent revolution through the ecliptic; and that they both start from the point A, at the same instant. The false sun is supposed to pass through the celestial equator in the same time, that the real one passes through the ecliptic, but not through the same meridians at the same time, so that the false sun arrives at the points 1, 2, 3, 4, and 5, at the time when the real sun arrives at the points *a*, *b*, C, and *c*. When the two suns were at A, the starting point, they were both on the same meridian. but when the fictitious sun comes to 1, and the real sun to *a*, they are not in the same meridian, but the real sun is westward of the fictitious one, the real sun being at *a*, while the false sun is on the meridian 1, consequently, as the earth turns on its axis from west to east, any particular place will

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In fig. 203, which is the celestial equator, and which the ecliptic? Through which of these circles does the false, and through which does the true sun pass? When the real sun arrives to *a*, and the false one to 1, are they both on the same meridian? Which is then most westward? When the two suns are at 1 and *a*, why will any meridian come first under the real sun? Were the true sun in place of the false one, why would the sun and clock agree?

come under the sun's real meridian, sooner than under the fictitious sun's meridian; that is, it will be 12 o'clock by the true sun, before it is 12 o'clock by the false sun, or by a true clock; but were the true sun in place of the false one, the sun and clock would agree. While the true sun is passing through that quarter of his orbit, from *a* to C, and the fictitious sun from 1 to 3, it will always be noon by the true sun before it is noon by the false sun, and during this period, the sun will be *faster* than the clock.

When the true sun arrives at C, and the false one at 3, they are both on the same meridian, and the sun and clock agree. But while the real sun is passing from C to B, and the false one from 3 to B, any meridian comes later under the true sun than it does under the false, and then it is noon by the sun after it is noon by the clock, and the sun is then said to be *slower* than the clock. At B, both suns are again on the same meridian, and then again the sun and clock agree.

We have thus followed the real sun through one half of his *true apparent* place in the heavens, and the false one through half the celestial equator, and have seen that the two suns, since leaving the point A, have been only twice on the same meridian at the same time. It has been supposed that the two suns passed through equal arcs, in equal times, the real sun through the ecliptic, and the false one through the equator. The place of the false sun may be considered as representing the place where the real sun would be, in case the earth's axis had no inclination, and consequently it agrees with the clock every 24 hours. But the true sun, as he passes round in the ecliptic, comes to the same meridian, sometimes sooner, and sometimes later, and in passing around the other half of the ecliptic, or in the other half year, the same variations succeed each other.

The two suns are supposed to depart from the point A, on the 20th of March, at which time the sun and clock coincide. From this time, the sun is *faster* than the clock, until the two suns come together at the point C, which is on the 21st of June, when the sun and clock again agree. From this period the sun is *slower* than the clock, until the 23d of September,

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While the suns are passing from A to C, and from 1 to 3, will the sun be faster or slower than the clock? When the two suns are at C, and 3, why will the sun and clock agree? While the real sun is passing from B to C, which is fastest, the clock, or sun? What does the place of the false sun represent, in fig. 203?

nd *faster* again until the 21st of December, at which time they agree as before.

We have thus seen how the inclination of the earth's axis, and the consequent obliquity of the equator to the ecliptic, causes the sun and clock to disagree, and on what days they would coincide, provided no other cause interfered with their agreement. But although the inclination of the earth's axis would bring the sun and clock together on the above-mentioned days, yet this agreement is counteracted by another cause, which is the elliptical form of the earth's orbit, and though the sun and clock do agree four times in the year, it is not on any of the days above mentioned.

It has been shown by fig. 193, that the earth moves more rapidly in one part of its orbit than in another. When it is nearest the sun, which is in the winter, its velocity is greater, than when it is most remote from him, as in the summer. Were the earth's orbit a perfect circle, the sun and clock would coincide on the days above specified, because then the only disagreement would arise from the inclination of the earth's axis. But since the earth's distance from the sun is constantly changing, her rate of velocity also changes, and she passes through unequal portions of her orbit in equal times. Hence on some days, she passes through a greater portion of it than on others, and thus this becomes another cause of the inequality of the sun's apparent motion.

The elliptical form of the earth's orbit would prevent the coincidence of the sun and clock at all times, except when the earth is at the greatest distance from the sun, which happens on the 1st of July, and when she is at the least distance from him, which happens on the 1st of January. As the earth moves faster in the winter than in the summer, from this cause, the sun would be faster than the clock from the 1st of July to the 1st of January, and then slower than the clock from the 1st of January to the 1st of July.

We have now explained, separately, the two causes which prevent the coincidence of the sun and clock. By the first cause, which is the inclination of the earth's axis, they would

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The inclination of the earth's axis would make the sun and clock agree in March, and the other months above named: why then do they not actually agree at those times? Were the earth's orbit a perfect circle, on what days would the sun and clock agree? How does the form of the earth's orbit interfere with the agreement of the sun and clock on those days? At what times would the form of the earth's orbit bring the sun and clock to agree?

agree four times in the year, and by the second cause, the irregularity of the earth's motion, they would coincide only twice in the year.

Now these two causes counteract the effects of each other, so that the sun and clock do not coincide on any of the days, when either cause, taken singly, would make an agreement between them. The sun and clock, therefore, are together, only when the two causes balance each other; that is, when one cause so counteracts the other, as to make a mutual agreement between them. This effect is produced four times in the year; namely, on the 15th of April, 15th of June, 31st of August, and 24th of December. On these days, the sun and a clock keeping exact time, coincide, and on no others. The greatest difference between the sun and clock, or between apparent and mean time, is 16¼ minutes, which takes place about the 1st of November.

Precession of the Equinoxes.

A *tropical* year is the time it takes the sun to pass from one equinox, or tropic, to the same tropic; or equinox, again.

A *siderial* year is the time it takes the sun to perform his apparent annual revolution, from a fixed star, to the same fixed star again.

Now it has been found that these two complete revolutions are not finished in exactly the same time, but that it takes the sun about 20 minutes longer to complete his apparent revolution in respect to the *star*, than it does in respect to the *equinox*, and hence the siderial year is about 20 minutes longer than the tropical year. The revolution of the earth from equinox to equinox, again, therefore *precedes* its complete revolution in the ecliptic by about 20 minutes, for the absolute revolution of the earth is measured by its return to the fixed star, and not by the return of the sun to the same equinoctial point. This apparent falling back of the equinoctial point, so as to make the time when it meets the sun *precede* the time

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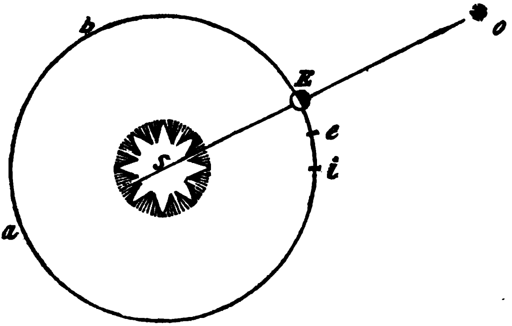
The inclination of the earth's axis would make the sun and clock agree four times in the year, and the form of the earth's orbit would make them agree twice in the year, now show the reason why they do not agree from these causes, on the above mentioned days, and why they do agree on other days. On what days do the sun and clock agree? What is a tropical year? What is a siderial year? What is the difference in the time which it takes the sun to complete his revolution in respect to a star, and in respect to the equinox? Explain what is meant by the precession of the equinoxes.

when the earth makes its complete revolution in respect to the star, is called the *precession of the equinoxes.*

The distance which the sun thus gains upon the fixed star, or the difference between the sun and star, when the sun has arrived at the equinoctial point, amounts to 50 seconds of a degree, thus making the equinoctial point recede 50 seconds of a degree, (when measured by the signs of the zodiac,) westward, every year, contrary to the sun's annual progressive motion in the ecliptic.

Fig. 204.



To illustrate this by a figure, suppose *S*, fig. 204, to be the sun, *E* the earth, and *o* a fixed star, all in a straight line with respect to each other. Let it be supposed that this opposition takes place on the 21st of March, at the vernal equinox, and that at that time the earth is exactly between the sun and the star. Now when the earth has performed a complete revolution around its orbit *b*, *a*, as measured by the star, she will arrive at precisely the same point where she now is. But it is found that when the earth comes to the same equinoctial point, the next year, she has not gone her complete revolution in respect to the star; the equinoctial point having fallen back with respect to the star, during the year, from *E* to *e*, so that the earth, after ving completed her revolution, in respect to

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How many seconds of a degree does the equinox recede every year, when the sun's place is compared with a star? How does fig. 204, illustrate the precession of the equinoxes? Explain fig. 204, and show from what points the equinoxes fall back from year to year.

the equinox, has yet to pass the space from *e* to E, to complete her revolution in respect to the star.

The space from *E* to *e*, being 50 seconds of a degree, and the equinoctial point falling this space every year short of the place where the sun and this point agreed the year before, it is obvious, that on the next revolution of the earth, the equinox will not be found at *e*, but at *i*, so that the earth, having completed her second revolution in respect to the sun when at *i*, will still have to pass from *i* to *E*, before she completes another revolution in respect to the star.

The precession of the equinoxes, being 50 seconds of a degree, every year, contrary to the sun's apparent motion, or about 20 minutes in time, short of the point where the sun and equinoxes coincided the year before, it follows, that the fixed stars, or those in the sign of the zodiac, move forward every year 50 seconds, with respect to the equinoxes.

In consequence of this precession, in 2160 years, those stars which now appear in the beginning of the sign Aries, for instance, will then appear in the beginning of Taurus, having moved forward one whole sign, or 30 degrees, with respect to the equinoxes, or the equinoxes having gone backwards 30 degrees, with respect to the stars. In 12,960 years, or 6 times 2160 years, therefore, the stars will appear to have moved forward one half of the whole circle of the heavens, so that those which now appear in the first degree of the sign Aries, will then be in the opposite point of the zodiac, and therefore, in the first degree of Libra. And in 12,690 years more, because the equinoxes will have fallen back the other half of the circle, the stars will appear to have gone forward, from Libra to Aries, thus completing the whole circle of the zodiac.

Thus in about 26,000 years the equinox will have gone backwards a whole revolution around the axis of the ecliptic, and the stars will appear to have gone forward the whole circle of the zodiac.

The discovery of the precession of the equinoxes has thrown much light on ancient astronomy and chronology, by showing an agreement between ancient and modern observations, con-

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How many minutes, in time, is the precession of the equinoxes per year? What effect does this precession produce on the fixed stars? How many years is a star in going forward one degree, in respect to the equinoxes? In how many years will the stars appear to have passed half around the heavens? In what period will the earth appear to have gone backwards one whole revolution? In what respect is the precession of the equinoxes an important subject?

cerning the places of the signs of the zodiac, not to be reconciled in any other manner.

A complete explanation of the cause which occasions the precession of the equinoxes, would require the aid of the most abstruse mathematics, and therefore cannot be properly introduced here. The cause itself may, however, be stated in a few words.

It has already been explained, that the revolution of the earth round its axis, has caused an excess of matter to be accumulated at the equator, and hence, that the equatorial, is greater than the polar diameter, by 34 miles. Now the attraction of the sun, and moon, on this accumulated matter at the equator, has the effect of slowly turning the earth about the axis of the ecliptic, and thus causing the precession of the equinoxes.

The Moon.

While the earth revolves round the sun, the moon revolves round the earth, completing her revolution once in 27 days, 7 hours, and 43 minutes, and at the distance of 240,000 miles from the earth. The period of the moon's change, that is, from new moon to new moon again, is 29 days, 12 hours, and 44 minutes.

The time of the moon's revolution round the earth is called her *periodical* month; and the time from change to change is called her *synodical* month. If the earth had no annual motion, these two periods would be equal, but because the earth goes forward in her orbit, while the moon goes round the earth, the moon must go as much farther, from change to change, to make these periods equal, as the earth goes forward during that time, which is more than the twelfth part of her orbit, there being more than twelve lunar periods in the year.

These two revolutions may be familiarly illustrated by the motions of the hour and minute hands of a watch. Let us suppose the 12 hours marked on the dial plate of a watch to represent the 12 signs of the zodiac through which the sun seems to pass in his yearly revolution, while the hour hand of

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What is the cause of the precession of the equinoxes? What is the period of the moon's revolution round the earth? What is the period from new moon to new moon again? What are these two periods called? Why are not the periodical and synodical months equal? How are these two revolutions of the moon illustrated by the two hands of a watch?

the watch represents the sun, and the minute hand the moon. Then, as the hour hand goes around the dial plate once in 12 hours, so the sun apparently goes around the zodiac once in 12 months; and as the minute hand makes 12 revolutions to one of the hour hand, so the moon makes 12 revolutions to one of the sun. But the moon, or minute hand, must go more than once round, from any point on the circle, where it last came in conjunction with the sun, or hour hand, to overtake it again, since the hour hand will have moved forward of the place where it was last overtaken, and consequently the next conjunction must be forward of the place where the last happened. During an hour, the hour hand describes the twelfth part of the circle, but the minute hand has not only to go round the whole circle in an hour, but also such a portion of it, as the hour hand has moved forward since they last met. Thus at 12 o'clock, the hands are in conjunction; the next conjunction is 5 minutes 27 seconds past I o'clock; the next, 10 min. 54 sec. past II o'clock; the third, 16 min. 21 sec. past III; the 4th, 21 min. 49 sec. past IV: the 5th, 27 min. 10 sec. past V; the 6th, 32 min. 43 sec. past VI; the 7th, 38 min. 10 sec. past VII; the 8th, 43 min. 38 sec. past VIII; the 9th, 49 min. 5 sec. past IX; the 10th, 54 min. 32 sec. past X; and the next conjunction is at XII.

Now although the moon passes around the earth in 27 days 7 hours and 43 minutes, yet her change does not take place at the end of this period, because her changes are not occasioned by her revolutions alone, but by her coming periodically into the same position in respect to the sun. At her change, she is in conjunction with the sun, when she is not seen at all, and at this time astronomers call it *new moon*, though generally, we say it is new moon two days afterwards, when a small part of her face is to be seen. The reason why there is not a new moon at the end of 27 days, will be obvious, from the motions of the hands of a watch; for we see that more than a revolution of the minute hand is required to bring it again in the same position with the hour hand, by about the twelfth part of the circle.

The same principle is true in respect to the moon; for as

Mention the time of several conjunctions between the two hands of a watch. Why do not the moon's changes take place at the periods of her revolution around the earth? How much longer does it take the moon to come again in conjunction with the sun, than it does to perform her periodical revolution?

the earth advances in its orbit, it takes the moon 2 days 5 hours and 1 minute longer to come again in conjunction with the sun, than it does to make her monthly revolution round the earth; and this 2 days 5 hours and 1 minute being added to 27 days 7 hours and 43 minutes, the time of the periodical revolution makes 29 days 12 hours and 44 minutes, the period of her synodical revolution.

The moon always presents the same side, or face, towards the earth, and hence it is evident that she turns on her axis but once, while she is performing one revolution round the earth, so that the inhabitants of the moon have but one day, and one night, in the course of a lunar month.

One half of the moon is never in the dark, because when this half is not enlightened by the sun, a strong light is reflected to her from the earth, during the sun's absence. The other half of the moon enjoys alternately two weeks of the sun's light, and two weeks of total darkness.

The moon is a globe, like our earth, and, like the earth, shines only by the light reflected from the sun; therefore, while that half of her which is turned towards the sun is enlightened, the other half is in darkness. Did the moon shine by her own light, she would be constantly visible to us, for then, being an orb, and every part illuminated, we should see her constantly full and round, as we do the sun.

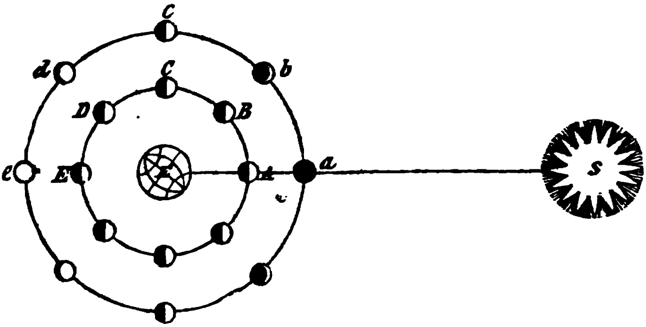
One of the most interesting circumstances to us, respecting the moon, is, the constant changes which she undergoes, in her passage around the earth. When she first appears, a day or two after her change, we can see only a small portion of her enlightened side, which is in the form of a crescent; and at this time she is commonly called new moon. From this period, she goes on increasing, or showing more and more of her face every evening, until at last she becomes round, and her face fully illuminated. She then begins again to decrease, by apparently losing a small section of her face, and the next evening, another small section from the same part, and so on, decreasing a little every day, until she entirely disappears; and having been absent a day or two, re-appears, in the form of a crescent, or new moon, as before.

How is it proved that the moon makes but one revolution on her axis, as she passes around the earth? One half of the moon is never in the dark; explain why this is so. How long is the day and night at the other half? How is it shown that the moon shines only by reflected light?

When the moon disappears, she is said to be in conjunction, that is, she is in the same direction from us with the sun. When she is full, she is said to be in *opposition*, that is, she is in that part of the heavens opposite to the sun, as seen by us.

The different appearances of the moon, from *new* to *full*, and from full to *change*, are owing to her presenting different portions of her enlightened surface towards us at different times. These appearances are called the *phases* of the moon, and are easily accounted for, and understood, by the following figure

Fig. 205.



Let *S*, fig. 205, be the sun, *E* the earth, and *A*, *B*, *C*, *D*, *E*, the moon in different parts of her orbit. Now when the moon changes, or is in conjunction with the sun, as at *A*, her dark side is turned towards the earth, and she is invisible, as represented at *a*. The sun always shines on one half of the moon, in every direction, as represented at *A* and *B*, on the inner circle; but we at the earth can see only such portions of the enlightened half as are turned towards us. After her change, when she has moved from *A* to *B*, a small part of her illuminated side comes in sight, and she appears horned, as at *b*, and is then called the *new* moon. When she arrives at *C*, several days afterwards, one half of her disc is visible, and she appears as at *c*, her appearance being the same in both circles. At this point she is said to be in her *first quarter*, because she has passed through a quarter of her orbit, and is 90 degrees

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When is the moon said to be in conjunction with the sun, and when in opposition to the sun? What are the phases of the moon? Describe fig. 205, and show how the moon passes from change to full, and from full to change.

from the place of her conjunction with the sun. At *D*, she shows us still more of her enlightened side, and is then said to appear *gibbous*, as at *d*. When she comes to *E*, her whole enlightened side is turned towards the earth, and she appears in all the splendor of a *full* moon. During the other half of her revolution, she daily shows less and less of her illuminated side, until she again becomes invisible by her conjunction with the sun. Thus in passing from her conjunction *a*, to her full, *e*, the moon appears every day to increase, while in going from her full to her conjunction again, she appears to us constantly to decrease, but as seen from the sun, she appears always full.

The earth, seen by the inhabitants of the moon, exhibits the same phases that the moon does to us, but in a contrary order. When the moon is in her conjunction, and consequently invisible to us, the earth appears full to the people of the moon, and when the moon is full to us, the earth is dark to them.

The earth appears thirteen times larger to the lunarians than the moon does to us. As the moon always keeps the same side towards the earth, and turns on her axis only as she moves round the earth, we never see her opposite side. Consequently, the lunarians who live on the opposite side to us never see the earth at all. To those who live on the middle of the side next to us, our earth is always visible, and directly over head, turning on its axis nearly thirty times as rapidly as the moon, for she turns only once in about thirty days. A lunar astronomer, who should happen to live directly opposite to that side of the moon, which is next to us, would have to travel a quarter of the circumference of the moon, or about 1500 miles, to see our earth above the horizon, and if he had the curiosity to see such a glorious orb, in its full splendor over his head, he must travel 3000 miles. But if his curiosity equalled that of the terrestrials, he would be amply compensated by beholding so glorious a nocturnal luminary, a moon thirteen times as large as ours.

That the earth shines upon the moon as the moon does upon us, is proved by the fact that the outline of her whole disc may

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What is said concerning the phases of the earth, as seen from the moon? When does the earth appear full at the moon? When is the earth, in her change, to the people of the moon? Why do those who live on one side of the moon never see the earth? How is it known that the earth shines upon the moon, as the moon does upon us?

be seen, when only a part of it is enlightened by the sun. Thus when the sky is clear, and the moon only two or three days old, it is not uncommon to see the brilliant new moon, with her horns enlightened by the sun, and at the same time, the old moon faintly illuminated by reflection from the earth. This phenomenon is sometimes called "the old moon in the new moon's arms."

It was a disputed point among former astronomers, whether the moon has an atmosphere; but the more recent discoveries have decided that she has an atmosphere, though there is reason to believe that it is much less dense than ours.

When the moon's surface is examined through a telesocpe, it is found to be wonderfully diversified, for besides the dark spots perceptible to the naked eye, there are seen extensive valleys, and long ridges of highly elevated mountains.

Some of these mountains, according to Dr. Herschel, are 4 miles high, while hollows more than 3 miles deep, and almost exactly circular, appear excavated on the plains. Astronomers have been at vast labor to enumerate, figure, and describe, the mountains and spots on the surface of the moon, so that the latitude and longitude of about 100 spots have been ascertained, and their names, shapes, and relative positions given. A still greater number of mountains have been named, and their heights and the length of their bases detailed.

The deep caverns, and broken appearance of the moon's surface, long since induced astronomers, to believe that such effects were produced by volcanoes, and more recent discoveries have seemed to prove that this suggestion was not without foundation. Dr. Herschel saw with his telescope, what appeared to him three volcanoes in the moon, two of which were nearly extinct, but the third was in the actual state of eruption, throwing out fire, or other luminous matter, in vast quantities.

It was formerly believed that several large spots, which appeared to have plane surfaces, were seas, or lakes, and that a part of the moon's surface was covered with water, like that of our earth. But it has been found, on closely observing these spots, when they were in such a position as to reflect the sun's light to the earth, had they been water, that no such reflection took place. It has also been found, that when

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What is said concerning the moon's atmosphere? How high are some of the mountains, and how deep the caverns of the moon? What is said concerning the volcanoes of the moon?

these spots were turned in a certain position, their surfaces appeared rough, and uneven; a certain indication that they are not water. These circumstances, together with the fact, that the moon's surface is never obscured by mist or vapor, arising from the evaporation of water from her surface, have induced astronomers to believe, that the moon has neither seas, lakes, nor rivers, and indeed that no water exists there.

Eclipses

Every planet and satellite in the solar system is illuminated by the sun, and hence they cast shadows in the direction opposite to him, just as the shadow of a man reaches from the sun. A shadow is nothing more than the interception of the rays of light by an opaque body. The earth always makes a shadow, which reaches to an immense distance into open space, in the direction opposite to the sun. When the earth, turning on its axis, carries us out of the sphere of the sun's light, we say it is *sun-set*, and then we pass into the earth's shadow, and night comes on. When the earth turns half round from this point, and we again emerge out of the earth's shadow, we say, the *sun rises*, and then day begins.

Now an eclipse of the moon is nothing more than her falling into the shadow of the earth. The moon having no light of her own, is thus darkened, and we say she is *eclipsed*. The shadow of the moon also reaches to a great distance from her. We know that it reaches at least 240,000 miles, because it sometimes reaches the earth. An eclipse of the sun is occasioned whenever the earth falls into the shadow of the moon. Hence in eclipses, whether of the sun or moon, the two planets and the sun must be nearly in a straight line with respect to each other. In eclipses of the moon, the earth is between the sun and moon, and in eclipses of the sun, the moon is between the earth and sun.

If the moon went around the sun in the same plane with the earth, that is, were the moon's orbit on the plane of the

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What is supposed concerning the lakes and seas of the moon? On what grounds is it supposed that there is no water at the moon? What is a shadow? When do we say it is sun-set, and when do we say it is sun-rise? What occasions an eclipse of the moon? What causes eclipses of the sun? In eclipses of the moon, what planet is between the sun and moon? In eclipses of the sun, what planet is between the sun and earth? Why is there not an eclipse of the sun at every conjunction of the sun and moon?

ecliptic, there would happen an eclipse of the sun at every conjunction of the sun and moon, or at the time of every new moon. But at these conjunctions, the moon does not come exactly between the earth and sun, because the orbit of the moon is inclined to the ecliptic at an angle of 5⅓ degrees. Did the planes of the orbits of the earth and moon coincide, there would be an eclipse of the moon at every full, for then the moon would pass exactly through the earth's shadow.

One half of the moon's orbit being elevated 5⅓ degrees above the ecliptic, the other half is depressed as much below it, and thus the moon's orbit crosses that of the earth in two opposite points, called the moon's *nodes*.

As the nodes of the moon are the points where she crosses the ecliptic, she must be half the time above, and the other half below these points. The node in which she crosses the plane of the ecliptic upward, or towards the north, is called her *ascending* node. That in which she crosses the same plane downward, or toward the south, is called her *descending* node.

The moon's orbit, like those of the other planets, is elliptical, so that she is sometimes nearer the earth than at others. When she is in that part of her orbit, at the greatest distance from the earth, she is said to be in her *apogee*, and when at her least distance from the earth, she is in her *perigee*.

Eclipses can only happen at the time when the moon is at, or near, one of her nodes, for at no other time is she near the plane of the earth's orbit; and since the earth is always in this plane, the moon must be at, or near it also, in order to bring the two planets and the sun in the same right line, without which no eclipse can happen.

The reason why eclipses do not happen oftener, and at regular periods, is because a node of the moon is usually only twice, and never more than three times in the year, presented towards the sun. The average number of total eclipses of both luminaries, in a century, is about thirty, and the average number of total and partial, in a year, about four. There may be seven eclipses in a year, including those of both lu-

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How many degrees is the moon's orbit inclined to that of the earth? What are the nodes of the moon? What is meant by the ascending and descending nodes of the moon? What is the moon's apogee, and what her perigee? Why must the moon be at, or near, one of her nodes, to occasion an eclipse? Why do not eclipses happen often, and at regular periods? What is the greatest, and what the least number of eclipses, that can happen in a year?

minaries, and there may be only two. When there are only two, they are both of the sun.

When the moon is within 16½ degrees of her node, at the time of her change, she is so near the ecliptic, that the sun may be more or less eclipsed, and when she is within 12 degrees of her node, at the time of her full, the moon will be more or less eclipsed.

But the moon is more frequently within 16½ degrees of her node at the time of her change, than she is within 12 degrees at the time of her full, and consequently there will be a greater number of solar, than of lunar eclipses, in a course of years. Yet more lunar eclipses will be visible, at any one place on the earth, than solar, because the sun, being so much larger than the earth, or moon, the shadow of these bodies must terminate in a point, and this point of the moon's shadow never covers but a small portion of the earth's surface, while lunar eclipses are visible over a whole hemisphere, and as the earth turns on its axis, are therefore visible to more than half the earth. This will be obvious by figs. 206 and 207, where it will be observed that an eclipse of the moon may be seen wherever the moon is visible, while an eclipse of the sun will be total only to those who live within the space covered by the moon's dark shadow.

Lunar Eclipses.—When the moon falls into the shadow of the earth, the rays of the sun are intercepted, or hid from her, and she then becomes eclipsed. When the earth's shadow covers only a part of her face, as seen by us, she suffers only a *partial* eclipse, one part of her disc being obscured, while the other part reflects the sun's light. But when her whole surface is obscured by the earth's shadow, she then suffers a *total* eclipse, and of a duration proportionate to the distance she passes through the earth's shadow.

Fig. 206 represents a total lunar eclipse; the moon being in the midst of the earth's shadow. Now it will be apparent, that in the situation of the sun, earth, and moon, as represented in the figure, this eclipse will be visible from all parts of

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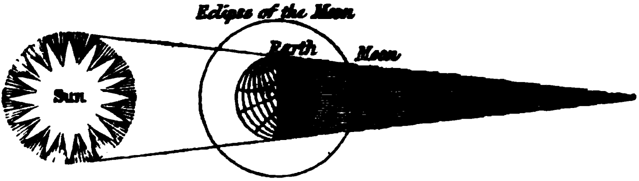
Why will there be more solar than lunar eclipses, in the course of years? Why will more lunar than solar eclipses be visible at any one place?

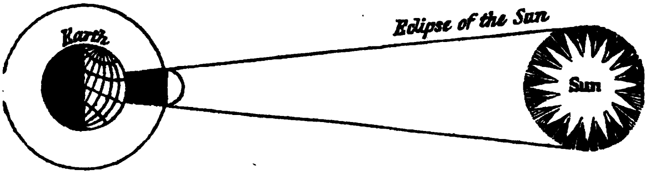
that hemisphere of the earth which is next the moon, and that the moon's disc will be equally obscured, from whatever point it is seen. When the moon passes through only a part of the earth's shadow, then she suffers only a partial eclipse, but this is also visible from the whole hemisphere next the moon. It will be remembered that lunar eclipses happen only at full moon, the sun and moon being in opposition, and the earth between them.

Fig. 206.



Solar Eclipses.—When the moon passes between the earth and sun, there happens an eclipse of the sun, because then the moon's shadow falls upon the earth. A total eclipse of the sun happens often, but when it occurs, the total obscurity is confined to a small part of the earth: since the dark portion of the moon's shadow never exceeds 200 miles in diameter on the earth. But the moon's partial shadow, or *penumbra*, may cover a space on the earth of more than 4000 miles in diameter, within all which space the sun will be more or less eclipsed. When the penumbra first touches the earth, the eclipse begins at that place, and ends when the penumbra leaves it. But the eclipse will be total only where the dark shadow of the moon touches the earth.

Fig. 207.



Why is the same eclipse total at one place, and only partial at another?
Why is a total eclipse of the sun confined to so small a part of the earth?

Fig. 207 represents an eclipse of the sun, without regard to the penumbra, that it may be observed how small a part of the earth the dark shadow of the moon covers. To those who live within the limits of this shadow, the eclipse will be total, while to those who live in any direction around it, and within reach of the penumbra, it will be only partial.

Solar eclipses are called *annular*, from *annulus*, a ring, when the moon passes across the centre of the sun, hiding all his light, with the exception of a ring on his outer edge, which the moon is too small to cover from the position in which it is seen.

Fig. 208.

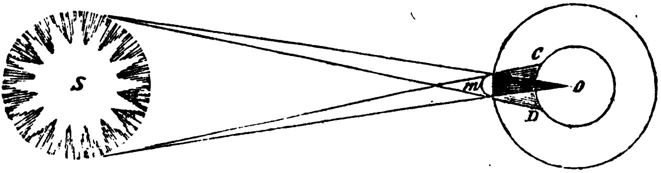


Fig. 208 represents a solar eclipse, with the penumbra D, C, and the *umbra*, or dark shadow, as seen in the above figure.

When the moon is at its greatest distance from the earth, its shadow *m o*, sometimes terminates, before it reaches the earth, and then an observer standing directly under the point *o*, will see the outer edge of the sun, forming a bright ring around the circumference of the moon, thus forming an *annular* eclipse.

The penumbra *D C*, is only a partial interception of the sun's rays, and in annular eclipses it is this partial shadow only which reaches the earth, while the umbra, or dark shadow, terminates in the air. Hence annular eclipses are never total in any part of the earth. The penumbra, as already stated, may cover more than 4000 miles of space, while the umbra never covers more than 200 miles in diameter; hence partial eclipses of the sun may be seen by a vast number of inhabitants, while comparatively few will witness the total eclipse.

When there happens a total solar eclipse to us, we are eclipsed to the moon, and when the moon is eclipsed to us, an eclipse of the sun happens to the moon. To the moon, an eclipse

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What is meant by penumbra? What will be the difference in the aspect of the eclipse, whether the observer stands within the dark shadow, or only within the penumbra? What is meant by annular eclipses? Are annular eclipses ever total in any part of the earth? In annular eclipses, what part of the moon's shadow reaches the earth?

of the earth can never be total, since her shadow covers only a small portion of the earth's surface. Such an eclipse, therefore, at the moon, appears only as a dark spot on the face of the earth; but when the moon is eclipsed to us, the sun is partially eclipsed to the moon for several hours longer than the moon is eclipsed to us.

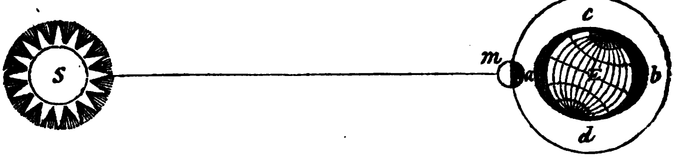
The Tides.

The ebbing and flowing of the sea, which regularly takes place twice in 24 hours, are called the *tides*. The cause of the tides, is the attraction of the sun and moon, but chiefly of the moon, on the waters of the ocean. In virtue of the universal principle of gravitation, heretofore explained, the moon, by her attraction, draws, or raises the water towards her, but because the power of attraction diminishes as the squares of the distances increase, the waters, on the opposite side of the earth, are not so much attracted as they are on the side nearest the moon. This want of attraction, together with the greater centrifugal force of the earth on its opposite side, produced in consequence of its greater distance from the common centre of gravity, between the earth and moon, causes the waters to rise on the opposite side, at the same time that they are raised by direct attraction on the side nearest the moon.

Thus the waters are constantly elevated on the sides of the earth opposite to each other above their common level, and consequently depressed at opposite points equally distant from these elevations.

Let *m*, fig. 209, be the moon, and *E* the earth covered with water. As the moon passes round the earth, its solid and fluid parts are equally attracted by her influence according to their densities; but while the solid parts are at liberty to move only as a whole, the water obeys the slightest impulse, and thus tends towards the moon where her attraction is the strongest.

Fig. 209.



What is said concerning eclipses of the earth, as seen from the moon? What are the tides? What is the cause of the tides? What causes the tide to rise on the side of the earth opposite to the moon?

Consequently the waters are perpetually elevated immediately under the moon. If therefore the earth stood still, the influence of the moon's attraction would raise the tides only as she passed round the earth. But as the earth turns on her axis every 24 hours, and as the waters nearest the moon, as at *a*, are constantly elevated, they will, in the course of 24 hours, move round the whole earth, and consequently from this cause there will be high water at every place once in 24 hours. As the elevation of the waters under the moon causes their depression at 90 degrees distance on the opposite sides of the earth *d* and *c*, the point *c* will come to the same place, by the earth's diurnal revolution, six hours after the point *a*, because *c* is one quarter the circumference of the earth from the point *a*, and therefore there will be low water at any given place six hours after it was high water at that place. But while it is high water under the moon, in consequence of her direct attraction, it is also high water on the opposite side of the earth in consequence of her diminished attraction, and the earth's centrifugal motion, and therefore it will be high water from this cause twelve hours after it was high water from the former cause, and six hours after it was low water from both causes.

Thus, when it is high water at *a* and *b*, it is low water at *c* and *d*, and as the earth revolves once in 24 hours, there will be an alternate ebbing and flowing of the tide, at every place, once in six hours.

But while the earth turns on her axis, the moon advances in her orbit, and consequently any given point on the earth will not come under the moon on one day so soon as it did on the day before. For this reason, high or low water at any place comes about fifty minutes later on one day than it did the day before.

Thus far we have considered no other attractive influence except that of the moon, as affecting the waters of the ocean. But the sun, as already observed, has an effect upon the tides, though on account of his great distance, his influence is small when compared with that of the moon.

When the sun and moon are in conjunction, as represented in fig. 209, which takes place at her change, or when they are

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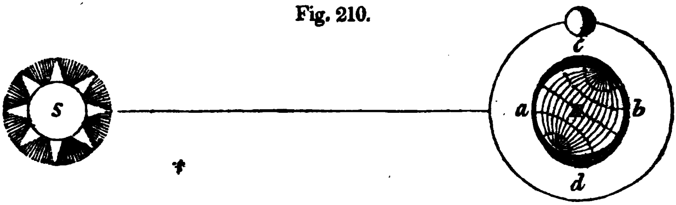
If the earth stood still, the tides would rise only as the moon passes round the earth; what, then, causes the tides to rise twice in 24 hours? When it is high water under the moon by her attraction, what is the cause of high water on the opposite side of the earth, at the same time? Why are the tides about 50 minutes later every day?

in opposition, which takes place at full moon, then their forces are united, or act on the waters in the same direction, and consequently the tides are elevated higher than usual, and on this account are called *spring tides.*

But when the moon is in her quadratures, or quarters, the attraction of the sun tends to counteract that of the moon, and although his attraction does not elevate the waters and produce tides, his influence diminishes that of the moon, and consequently the elevation of the waters are less when the sun and moon are so situated in respect to each other, than when they are in conjunction, or opposition.

Fig. 210.



This effect is represented by fig. 210, where the elevation of the tides at *c* and *d* is produced by the causes already explained; but their elevation is not so great as in fig. 206, since the influence of the sun acting in the direction *a b*, tends to counteract the moon's attractive influence. These small tides are called *neap tides*, and happen only when the moon is in her quadratures.

The tides are not at their greatest heights at the time when the moon is at its meridian, but sometime afterwards, because the water, having a motion forward, continues to advance by its own inertia, sometime after the direct influence of the moon has ceased to affect it.

Latitude and Longitude.

Latitude is the distance from the equator in a direct line, north or south, measured in degrees and minutes. The number of degrees is 90 north, and as many south, each line on which these degrees are reckoned running from the equator to the poles. Places at the north of the equator are in *north latitude*, and those south of the equator are in *south latitude*. The *parallels* of latitude are imaginary lines drawn parallel to

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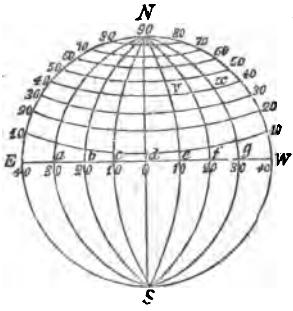
What produces spring tides? Where must the moon be in respect to the sun, to produce spring tides? What is the occasion of neap tides? What is latitude?

the equator, either north or south, and hence every place situated on the same parallel, is in the same latitude, because every such place must be at the same distance from the equator. The length of a degree of latitude is 60 geographical miles.

Longitude is the distance measured in degrees and minutes either east or west, from any given point, on the equator, or on any parallel of latitude. Hence the lines, or meridians of longitude cross those of latitude at right angles. The degrees of longitude are 180 in number, its lines extending half a circle to the east, and half a circle to the west, from any given meridian, so as to include the whole circumference of the earth. A degree of longitude, at the equator, is of the same length as a degree of latitude, but as the poles are approached, the degrees of longitude diminish in length, because the earth grows smaller in circumference, from the equator towards the poles; hence the lines surrounding it become less and less. This will be made obvious by fig. 211.

Fig. 211.



Let this figure represent the earth, *N* being the north pole, *S* the south pole, and *E W* the equator. The lines 10, 20, 30, and so on, are the parallels of latitude, and the lines *N a S N*, *b S*, &c. are meridian lines, or those of longitude.

The latitude of any place on the globe, is the number of degrees between that place and the equator, measured on a meridian line; thus *x* is in latitude 40 degrees, because the *x g* part of the meridian contains 40 degrees.

The longitude of a place is the number of degrees it is situated east or west from any meridian line; thus *v* is 20 degrees west longitude from *x*, and *x* is 20 degrees east longitude from *v*.

As the equator divides the earth into two equal parts, or hemispheres, there seems to be a natural reason why the de-

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How many degrees of latitude are there? How far do the lines of latitude extend? What is meant by north and south latitude? What are the parallels of latitude? What is longitude? How many degrees of longitude are there, east or west? What is the latitude of any place? What is the longitude of a place?

grees of latitude should be reckoned from this great circle. But from east to west there is no natural division of the earth, each meridian line being a great circle, dividing the earth into two hemispheres, and hence there is no natural reason why longitude should be reckoned from one meridian any more than another. It has, therefore, been customary for writers and mariners to reckon longitude from the capital of their own country, as the English from London, the French from Paris, and the Americans from Washington. But this mode, it is apparent, must occasion much confusion, since each writer of a different nation would be obliged to correct the longitude of all other countries, to make it agree with his own. More recently, therefore, the writers of Europe and America have selected the royal observatory, at Greenwich, near London, as the first meridian, and on most maps and charts lately published, longitude is reckoned from that place.

The latitude of any place is determined by taking the altitude of the sun at mid-day, and then subtracting this from 90 degrees, making proper allowances for the sun's place in the heavens. The reason of this will be understood, when it is considered that the whole number of degrees from the Zenith to the horizon is 90, and therefore, if we ascertain the sun's distance from the horizon, that is, his altitude, by allowing for the sun's declination north or south of the equator, and subtracting this from the whole number, the latitude of the place will be found. Thus, suppose that on the 20th of March, when the sun is at the equator, his altitude from any place north of the equator should be found to be 48 degrees above the horizon; this, subtracted from 90, the whole number of the degrees of latitude, leaves 42, which will be the latitude of the place where the observation was made.

If the sun, at the time of observation, has a declination, north or south of the equator, this declination must be added to, or subtracted from, the meridian altitude, as the case may be. For instance, another observation being taken at the place where the latitude was found to be 42, when the sun had a declination of 8 degrees north, then his altitude would be 8 degrees greater than before, and therefore 56, instead of

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Why are the degrees of latitude reckoned from the equator? What is said concerning the places from which the degrees of longitude have been reckoned? What is the inconvenience of estimating longitude from a place in each country? From what place is longitude reckoned in Europe and America?

48. Now, subtracting this 8, the sun's declination, from 56, and the remainder from 90, and the latitude of the place will be found 42, as before. If the sun's declination be south of the equator, and the latitude of the place north, his declination must be added to the meridian altitude, instead of being subtracted from it. The same result may be obtained by taking the meridian altitude of any of the fixed stars, whose declinations are known, instead of the sun's, and proceeding as above directed.

There is more difficulty in ascertaining the degrees of longitude, than those of latitude, because, as above stated, there is no fixed point, like that of the equator, from which its degrees are reckoned. The degrees of longitude are therefore estimated from Greenwich, and are ascertained by the following methods:

When the sun comes to the meridian of any place, it is noon, or 12 o'clock, at that place, and therefore, since the equator is divided into 360 equal parts, or degrees, and since the earth turns on its axis once in 24 hours, 15 degrees of the equator will correspond with one hour of time, for 360 degrees being divided by 24 hours, will give 15. The earth, therefore, moves in her daily revolution, at the rate of 15 degrees for every hour of time. Now, as the apparent course of the sun is from east to west, it is obvious that he will come to any meridian lying east of a given place, sooner than to one lying west of that place, and therefore it will be 12 o'clock to the east of any place, sooner than at that place, or to the west of it. When, therefore, it is noon at any one place, it will be 1 o'clock at all places 15 degrees to the east of it, because the sun was at the meridian of such places an hour before; and so, on the contrary, it will be 11 o'clock, 15 degrees west of the same place, because the sun has still an hour to travel, before he reaches the meridian of that place. It makes no difference, then, where the observer is placed, since if it is 12 o'clock where he is, it will be 1 o'clock 15 degees to the east of him, and 11 o'clock 15 degrees to the west of him, and so

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How is the latitude of a place determined? Give an example of the method of finding the latitude of the same place at different seasons of the year. When must the sun's declination from the equator be added to, and when subtracted from, his meridian altitude? Why is there more difficulty in ascertaining the degrees of longitude than of latitude? How many degrees of longitude does the surface of the earth pass through in an hour? Suppose it is noon at any given place, what o'clock will it be 15 degrees to the east of that place? Explain the reason. How may longitude be determined by an eclipse?

in this proportion, let the time be more or less. Now, if any celestial phenomenon should happen, such as an eclipse of the moon, or of Jupiter's satellites, the difference of longitude between two places where it is observed, may be determined by the difference of the times at which it appeared to take place. Thus, if the moon enters the earth's shadow at 6 o'clock in the evening, as seen at Philadelphia, and at half past 6 o'clock at another place, then this place is half an hour, or 7½ degrees, to the east of Philadelphia, because 7½ degrees of longitude are equal to half an hour of time. To apply these observations practically, it is only necessary that it should be known exactly at what time the eclipse takes place at a given point on the earth.

Longitude is also ascertained by means of a chronometer, or true time piece, adjusted to any given meridian; for if the difference between two clocks, situated east and west of each other, and going exactly at the same rate, can be known, at the same time, then the distance between the two meridians where the clocks are placed will be known, and the difference of longitude may be found.

Suppose two chronometers, which are known to go at exactly the same rate, are made to indicate 12 o'clock by the meridian line of Greenwich, and the one be taken to sea, while the other remains at Greenwich. Then suppose the captain, who takes his chronometer to sea, has occasion to know his longitude. In the first place, he ascertains, by an observation of the sun, when it is 12 o'clock at the place where he is, and then by his time piece, when it is 12 o'clock at Greenwich, and by allowing 15 degrees for every hour of the difference in time, he will know his precise longitude in any part of the world. For example, suppose the captain sails with his chronometer for America, and after being several weeks at sea, finds by observation, that it is 12 o'clock by the sun, and at the same time finds by his chronometer, that it is 4 o'clock at Greenwich. Then because it is noon at his place of observation after it is noon at Greenwich, he knows that his longitude is west from Greenwich, and by allowing 15 degrees for every hour of the difference, his longitude is ascertained.

Explain the principles on which longitude is determined by the chronometer. Suppose the captain finds by his chronometer that it is 12 o'clock, where he is, 6 hours later than at Greenwich, what then would be his longitude? Suppose he finds it to be 12 o'clock 4 hours earlier where he is, than at Greenwich, what then would be his longitude?

Thus, 15 degrees, multiplied by 4 hours, give 60 degrees of west longitude from Greenwich. If it is noon at the place of observation, before it is noon at Greenwich, then the captain knows that his longitude is east, and his true place is found in the same manner.

Fixed Stars.

The stars are called *fixed*, because they have been observed not to change their places with respect to each other. They may be distinguished by the naked eye from the planets of our system by their scintillations, or twinkling. The stars are divided into classes, according to their magnitudes, and are called stars of the first, second, and so on to the sixth magnitude. About 2000 stars may be seen with the naked eye in the whole vault of the heavens, though only about 1000 are above the horizon at the same time. Of these, about 17 are of the first magnitude, 50 of the 2d magnitude, and 150 of the 3d magnitude. The others are of the 4th, 5th, and 6th magnitudes, the last of which are the smallest that can be distinguished with the naked eye.

It might seem incredible, that on a clear night only about 1000 stars are visible, when on a single glance at the different parts of the firmament, their numbers appear innumerable. But this deception arises from the confused and hasty manner in which they are viewed, for if we look steadily on a particular portion of sky, and count the stars contained within certain limits, we shall be surprised to find their number so few.

As we have incomparably more light from the moon, than from all the stars together, it is absurd to suppose that they were made for no other purpose than to cast so faint a glimmering on our earth, and especially as a great proportion of them are invisible to our naked eyes. The nearest fixed stars to our system, from the most accurate astronomical calculations, cannot be nearer than 20,000,000,000,000, or 20 trillions of miles from the earth, a distance so immense, that light cannot pass through it in less than three years. Hence were these stars annihilated at the present time, their light would

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Why are the stars called fixed? How may the stars be distinguished from the planets? The stars are divided into classes, according to their magnitudes; how many classes are there? How many stars may be seen with the naked eye, in the whole firmament? Why does there appear to be more stars than there really are? What is the computed distance of the nearest fixed stars from the earth?

continue to flow towards us, and they would appear to be in the same situation to us, three years hence that they do now.

Our sun, seen from the distance of the nearest fixed stars, would appear no larger than a star of the first magnitude does to us. These stars appear no larger to us, when the earth is in that part of her orbit nearest to them, than they do, when she is in the opposite part of her orbit; and as our distance from the sun is 95,000,000, of miles, we must be twice this distance, or the whole diameter of the earth's orbit, nearer a given fixed star at one period of the year, than at another The difference, therefore, of 190,000,000 of miles, bears so small a proportion to the whole distance between us and the fixed stars, as to make no appreciable difference in their sizes, even when assisted by the most powerful telescopes.

The amazing distances of the fixed stars may also be inferred from the return of comets to our system, after an absence of several hundred years.

The velocity with which some of these bodies move, when nearest the sun, has been computed at nearly a million of miles in an hour, and although their velocities must be perpetually retarded, as they recede from the sun, still in 250 years of time, they must move through a space, which to us would be infinite. The periodical return of one comet is known to be upwards of 500 years, making more than 250 years in performing its journey to the most remote part of its orbit, and as many in returning back to our system; and that it must still always be nearer our system than the fixed stars, is proved by its return; for by the laws of gravitation, did it approach nearer another system it would never again return to ours.

From such proofs of the vast distances of the fixed stars, there can be no doubt that they shine with their own light, like our sun, and hence the conclusion that they are suns to other worlds, which move around them, as the planets do around our sun. Their distances will, however, prevent our ever knowing, except by conjecture, whether this is the case or not, since, were they millions of times nearer us than they

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How long would it take light to reach us from the fixed stars? How large would our sun appear at the distance of the fixed stars? What is said concerning the difference of the distance between the earth and the fixed stars at different seasons of the year, and of their different appearances in consequence? How may the distances of the fixed stars be inferred by the long absence and return of comets? On what grounds is it supposed that the fixed stars are suns to other worlds?

are, we should not be able to discover the reflected light of their planets.

Comets.

Besides the planets, which move round the sun in regular order and in nearly circular orbits, there belongs to the solar system an unknown number of bodies called *Comets*, which move round the sun in orbits exceedingly eccentric, or elliptical, and whose appearance among our heavenly bodies is only occasional. Comets, to the naked eye, have no visible disc, but shine with a faint glimmering light, and are accompanied by a train or tail, turned from the sun, and which is sometimes of immense length. They appear in every region of the heavens, and move in every possible direction.

In the days of ignorance and superstition, comets were considered the harbingers of war, pestilence, or some other great or general evil; and it was not until astronomy had made considerable progress as a science, that these strangers could be seen among our planets without the expectation of some direful event.

It had been supposed that comets moved in straight lines, coming from the regions of infinite, or unknown space, and merely passing by our system, on their way to regions equally unknown and infinite, and from which they never returned. Sir Isaac Newton was the first to demonstrate that comets pass round the sun, like the planets, but that their orbits are exceedingly elliptical, and extend out to a vast distance beyond the solar system.

The number of comets is unknown, though some astronomers suppose that there are nearly 500 belonging to our system. Ferguson, who wrote in about 1760, supposed that there were less than 30 comets which made us occasional visits; but since that period the elements of the orbits of nearly 100 of these bodies have been computed.

Of these, however, there are only three whose periods of return among us are known with any degree of certainty. The first of these has a period of 75 years; the second a period of 129 years; and the third a period of 575 years. The third appeared in 1680: and therefore cannot be expected again

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What number of comets are supposed to belong to our system? How many have had the elements of their orbits estimated by astronomers? How many are there whose periods of return are known?

until the year 2225. This comet, in 1680, excited the most intense interest among the astronomers of Europe, on account of its great apparent size and near approach to our system. In the most remote part of its orbit, its distance from the sun was estimated at about eleven thousand two hundred millions of miles. At its nearest approach to the sun, which was only about 50,000 miles, its velocity, according to Sir Isaac Newton, was 880,000 miles in an hour; and supposing it to have retained the sun's heat like other solid bodies, its temperature must have been about 2000 times that of red hot iron. The tail of this comet was at least 100 millions of miles long.

Fig. 212.

In the Edinburgh Encyclopedia, article *Astronomy*, there is the most complete table of comets yet published. This table contains the elements of 97 comets, calculated by different astronomers, down to the year 1808.

From this table it appears that 24 comets have passed between the sun and the orbit of Mercury; 33 between the orbits of Venus and the Earth; 15 between the orbits of the Earth and Mars; 3 between the orbits of Mars and Ceres; and 1 between the orbits of Ceres and Jupiter. It also appears by this table that 49 comets have moved round the sun from west to east, and 48 from east to west.

Of the nature of these wandering planets very little is known. When examined by a telescope, they appear like a mass of vapours surrounding a dark nucleus. When the comet is at its perihelion, or nearest the sun, its color seems to be heightened by the intense light or heat of that luminary, and it then often shines with more brilliancy than the planets. At this time the tail or train, which is always directly opposite to the sun, appears at its greatest length, but is commonly so transparent as to permit the fixed stars to be seen through it A variety of opinions have been advanced by astronomers concerning the nature and cause of these trains. Newton supposed that they were thin vapour, made to ascend by the sun's heat, as the smoke of a fire ascends from the earth; while Kepler maintained that it was the atmosphere of the comet driven behind it by the impulse of the sun's rays. Others

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What is said of the comet of 1680?

suppose that this appearance arises from streams of electric matter passing away from the comet, &c.

ELECTRICITY.

The science of *Electricity*, which now ranks as an important branch of Natural Philosophy, is wholly of modern date. The ancients were acquainted with a few detached facts dependent on the agency of electrical influence, but they never imagined that it was extensively concerned in the operations of nature, or that it pervaded material substances generally. The term electricity is derived from *electron*, the Greek name of amber, because it was known to the ancients, that when that substance was rubbed or excited, it attracted or repelled small light bodies, and it was then unknown that other substances when excited would do the same.

When a piece of glass, sealing wax, or amber, is rubbed with a dry hand, and held towards small and light bodies, such as threads, hairs, feathers, or straws, these bodies will fly towards the surface thus rubbed, and adhere to it for a short time. The influence by which these small substances are drawn, is called *electrical attraction*; the surface having this attractive power is said to be *excited*; and the substances susceptible of this excitation, are called *electrics*. Substances, not having this attractive power when rubbed, are called *non-electrics*.

The principal electrics are amber, rosin, sulphur, glass, the precious stones, sealing wax, and the fur of quadrupeds. But the metals, and many other bodies, may be excited when insulated and treated in a certain manner.

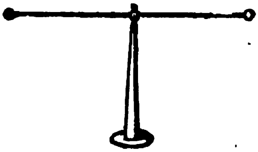
After the light substances, which had been attracted by the excited surface, have remained in contact with it a short time, the force which brought them together ceases to act, or acts in a contrary direction, and the light bodies are *repelled*, or thrown away from the excited surface. Two bodies, also, which have been in contact with the excited surface, mutually repel each other.

Various modes have been devised for exhibiting distinctly the attractive and repulsive agencies of electricity, and for obtaining indications of its presence, when it exists only in a feeble degree. Instruments for this purpose are termed *Electroscopes*.

From what is the term electricity derived? What is electrical attraction? What are electrics? What are non-electrics? What are the principal electrics? What is meant by electrical repulsion? What is an electroscope?

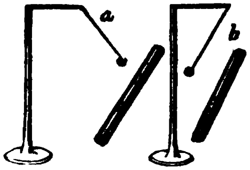
One of the simplest instruments of this kind consists of a metallic needle, terminated at each end by a light pith ball, which is covered with gold leaf, and supported horizontally at its centre by a fine point, fig. 213. When a stick of sealing wax, or a glass tube, is excited, and then presented to one of these balls, the motion of the needle on its pivot will indicate the electrical influence.

Fig. 213.



If an excited substance be brought near a ball made of pith, or cork, suspended by a silk thread, the ball will, in the first place, approach the electric as at *a*, fig. 214, indicating an attraction towards it, and if the position of the electric will allow, the ball will come into contact with the electric, and adhere to it for a short time, and will then recede from it, showing that it is repelled as at *b*. If now the ball which had touched the electric, be brought near another ball, which has had no communication with an excited substance, these two balls will attract each other, and come into contact; after which they will repel each other, as in the former case.

Fig. 214.



It appears, therefore, that the excited body, as the stick of sealing wax, imparts a portion of its electricity to the ball, and that when the ball is also electrified, a mutual repulsion then takes place between them. Afterwards, the ball, being electrified by contact with the electric, when brought near another ball not electrified, transfers a part of its electrical influence to that, after which these two balls repel each other as in the former instance.

Thus, when one substance has a greater or less quantity of electricity than another, it will attract the other substance, and when they are in contact, will impart to it a portion of this superabundance; but when they are both equally electrified, each having more or less than their natural quantity of electricity, they will repel each other.

When do two electrified bodies attract, and when do they repel each other?

To account for these phenomena, two theories have been advanced, one by Dr. Franklin, who supposes there is only one electrical fluid, and the other by Du Fay, who supposes there are two distinct fluids.

Dr. Franklin supposed that all terrestrial substances were pervaded with the electrical fluid, and that by exciting an electric, the equilibrium of this fluid was destroyed, so that one part of the excited body, contained more than its natural quantity of electricity, and the other part less. If in this state a conductor of electricity, as a piece of metal, be brought near the excited part, the accumulated electricity would be imparted to it, and then this conductor would receive more than its natural quantity of the electric fluid. This he called *positive* electricity. But if a conductor be connected with that part which has less than its ordinary share of the fluid, then the conductor parts with a share of its own, and therefore will then contain less than its natural quantity. This he called *negative* electricity. When one body *positively*, and another *negatively* electrified, are connected by a conducting substance, the fluid rushes from the positive to the negative body, and the equilibrium is restored. Thus bodies which are said to be positively electrified contain more than their natural quantity of electricity, while those which are negatively electrified contain less than their natural quantity.

The other theory is explained thus. When a piece of glass is excited and made to touch a pith ball, as above stated, then that ball will attract another ball, after which they will mutually repel each other, and the same will happen if a piece of sealing wax be used instead of the glass. But if a piece of excited glass, and another of wax, be made to touch two separate balls, they will attract each other; that is, the ball which received its electricity from the wax will attract that which received its electricity from the glass, and will be attracted by it. Hence Du Fay concludes that electricity consists of two distinct fluids, which exist together in all bodies—that they have a mutual attraction for each other—that they are separated by

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How will two bodies act, one having more, and the other less than the natural quantity of electricity, when brought near each other? How will they act when both have more or less than their natural quantity? Explain Dr. Franklin's theory of electricity. What is meant by positive, and what by negative electricity? What is the consequence, when a positive and a negative body are connected by a conductor? Explain Du Fay's theory. When two balls are electrified, one with glass, and the other with wax, will they attract or repel each other?

the excitation of electrics, and that when thus separated, and transferred to non-electrics, as to the pith balls, their mutual attraction causes the balls to rush towards each other. These two principles he called *vitreous* and *resinous* electricity. The vitreous being obtained from glass, and the resinous from wax, and other resinous substances.

Dr. Franklin's theory is by far the most simple, and will account for most of the electrical phenomena equally well with that of Du Fay, and therefore has been adopted by the most able and recent electricians.

It is found that some substances conduct the electric fluid from a positive to a negative surface with great facility, while others conduct it with difficulty, and others not at all. Substances of the first kind are called *conductors*, and those of the last, *non-conductors*. The electrics, or such substances as, being excited, communicate electricity, are all non-conductors, while the non-electrics, or such substances as do not communicate electricity on being merely excited, are conductors. The conductors are the metals, charcoal, water, and other fluids, except the oils ; also, smoke, steam, ice, and snow. The best conductors are gold, silver, platina, brass, and iron.

The electrics, or non-conductors, are glass, amber, sulphur, resin, wax, silk, most hard stones, and the furs of some animals.

A body is said to be *insulated*, when it is supported, or surrounded by an electric. Thus, a stool, standing on glass legs, is insulated, and a plate of metal laid on a plate of glass, is insulated.

When large quantities of the electric fluid are wanted for experiment, or for other purposes, it is procured by an *electrical machine.* These machines are of various forms, but all consist of an *electric* substance, of considerable dimensions; the *rubber* by which this is excited, the *prime conductor*, on which the electric matter is accumulated, the *insulator*, which prevents the fluid from escaping, and machinery by which the electric is set in motion.

What are the two electricities called ? From what substances are the two electricities obtained ? What are conductors ? What are non-conductors ? What substances are conductors ? What substances are the best conductors ? What substances are electrics, or non-conductors ? When is a body said to be insulated ? What are the several parts of an electrical machine ?

Fig. 215.

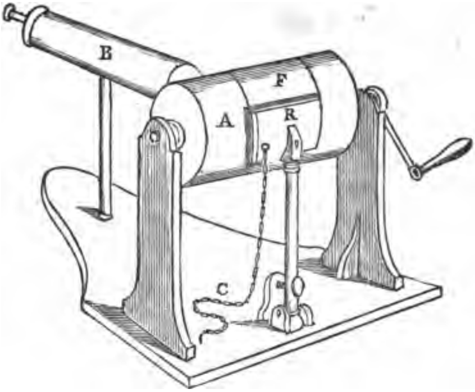

Fig. 215 represents such a machine, of which A is the electric, being a cylinder of glass; B the prime conductor, R the rubber or cushion, and C a chain connecting the rubber with the ground. The prime conductor is supported by a standard of glass. Sometimes, also, the pillars which support the axis of the cylinder, and that to which the cushion is attached, are made of the same material. The prime conductor has several wires inserted into its side, or end, which are pointed, and stand with the points near the cylinder. They receive the electric fluid from the glass and convey it to the conductor. The conductor is commonly made of sheet brass, there being no advantage in having it solid, as the electric fluid is always confined entirely to the surface. Even paper, covered with gold leaf, is as effective in this respect, as though the whole was of solid gold. The cushion is attached to a standard, which is furnished with a thumb screw, so that its pressure on the cylinder can be increased or diminished. The cushion is made of leather, stuffed, and at its upper edge there is attached a flap of silk, F, by which a greater surface of the glass is covered, and the electric fluid

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What is the use of the pointed wires in the prime conductor? How is it accounted for, that a mere surface of metal will contain as much electric fluid, as though it were solid? When a piece of glass, or sealing wax, is excited, by rubbing it with the hand, or a piece of silk, whence comes the electricity?

thus prevented, in some degree, from escaping. The efficacy of the rubber in producing the electric excitation is much increased by spreading on it a small quantity of an amalgam of tin and mercury, mixed with a little lard, or other unctuous substance.

The manner in which this machine acts, may be inferred from what has already been said, for when a stick of sealing wax, or a glass tube, is rubbed with the hand, or a piece of silk, the electric fluid is accumulated on the excited substance, and therefore must be transferred from the hand, or silk, to the electric. In the same manner, when the cylinder is made to revolve, the electric matter, in consequence of the friction, leaves the cushion, and is accumulated on the glass cylinder, that is, the cushion becomes negatively, and the glass positively electrified. The fluid, being thus excited, is prevented from escaping by the silk flap, until it comes to the vicinity of the metallic points, by which it is conveyed to the prime conductor. But if the cushion is insulated, the quantity of electricity obtained, will soon have reached its limit, for when its natural quantity has been transferred to the glass, no more can be obtained. It is then necessary to make the cushion communicate with the ground, which is done by laying the chain on the floor, or table, when more of the fluid will be accumulated, by further excitation, the ground being the inexhaustible source of the electric fluid.

If a person who is insulated, takes the chain in his hand, the electric fluid will be drawn from him, along the chain to the cushion, and from the cushion will be transferred to the prime conductor, and thus the person will become negatively electrified. If then, another person, standing on the floor, hold his knuckle near him who is insulated, a spark of electric fire will pass between them, with a crackling noise, and the equilibrium will be restored; that is, the electric fluid will pass from him who stands on the floor, to him who stands on the stool. But if the insulated person takes hold of a chain, connected with the prime conductor, he may be considered

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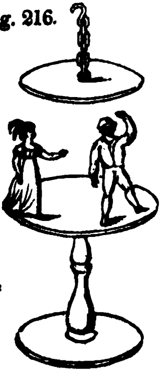
When the cushion is insulated, why is there a limited quantity of electric matter to be obtained from it? What is then necessary, that more electric matter may be obtained from the cushion? If an insulated person takes the chain, connected with the cushion, in his hand, what change will be produced in his natural quantity of electricity? If the insulated person takes hold of the chain connected with the prime conductor, and the machine be worked, what then will be the change produced in his electrical state?

as forming a part of the conductor, and therefore the electric fluid will be accumulated all over his surface, and he will be positively electrified, or will obtain more than his natural quantity of electricity. If now, a person standing on the floor touch this person, he will receive a spark of electrical fire from him, and the equilibrium will again be restored.

If two persons stand on two insulated stools, or if they both stand on a plate of glass, or a cake of wax, the one person being connected by the chain with the prime conductor, and the other with the cushion, then, after working the machine, if they touch each other, a much stronger shock will be felt, than in either of the other cases, because the difference between their electrical states will be greater, the one having more and the other less than his natural quantity of electricity. But if the two insulated persons both take hold of the chain connected with the prime conductor, or with that connected with the cushion, no spark will pass between them, on touching each other, because they will then both be in the same electrical state.

We have seen, fig. 213, that the pith ball is first attracted and then repelled, by the excited electric, and that the ball so repelled will attract, or be attracted, by other substances in its vicinity, in consequence of having received from the excited body more than its ordinary quantity of electricity.

Fig. 216.



These alternate movements are amusingly exhibited, by placing some small light bodies, such as the figures of men and women, made of pith, or paper, between two metallic plates, the one placed over the other, as in fig. 216, the upper plate communicating with the prime conductor, and the other with the ground. When the electricity is communicated to the upper plate, the little figures, being attracted by the electricity, will jump up, and strike their heads against it, and having received a portion of the fluid, are instantly repelled, and again attracted by the lower plate, to which they impart their elec-

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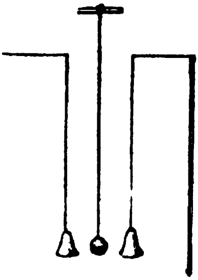
If two insulated persons take hold of the two chains, one connected with the prime conductor, and the other with the cushion, what changes will be produced?

tricity, and then are again attracted, and so fetch and carry the electric fluid from one to the other, as long as the upper plate contains more than the lower one. In the same manner, a tumbler, if electrified on the inside, and placed over light substances, as pith balls, will cause them to dance for a considerable time.

This alternate attraction and repulsion, by moveable conductors, is also pleasingly illustrated with a ball, suspended by a silk string between two bells of brass, fig. 217, one of the bells being electrified, and the other communicating with the ground. The alternate attraction and repulsion, moves the ball from one bell to the other, and thus producecs a continual ringing. In all these cases, the phenomena will be the same, whether the electricity be positive or negative; for two bodies, being both positively, or negatively electrified, repel each other, but if one be electrified positively, and the other negatively, or not at all, they attract each other.

Fig. 217.



Thus a small figure, in the human shape, with the head covered with hair, when electrified, either positively or negatively, will exhibit an appearance of the utmost terror, each hair standing erect, and diverging from the other, in consequence of mutual repulsion. A person standing on an insulated stool, and highly electrified, will exhibit the same appearance. In cold, dry weather, the friction produced by combing a person's hair, will cause a less degree of the same effect. In either case, the hair will collapse, or shrink to its natural state, on carrying a needle near it, because this conducts away the electric fluid. Instruments designed to measure the intensity of electric action, are called *electrometers*.

Such an instrument is represented by fig. 218. It consists of a slender rod of light wood, *a*, terminated by a pith ball, which serves as an index. This is suspended at the upper

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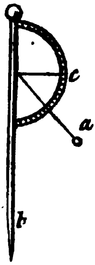
If they both take hold of the same chain, what will be the effect? Explain the reason why the little images dance between the two metallic plates, fig. 216. Explain fig. 217. Does it make any difference in respect to the motion of the images, or of the ball between the bells, whether the electricity be positive or negative? When a person is highly electrified, why does he exhibit an appearance of the utmost terror? What is an electrometer?

Fig. 218.



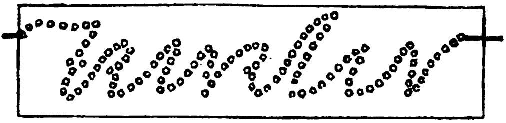
part of the wooden stem *b*, so as to play easily backwards and forwards. The ivory semicircle *c*, is affixed to the stem, having its centre coinciding with the axis of motion of the rod, so as to measure the angle of deviation from the perpendicular, which the repulsion of the ball from the stem produces in the index.

When this instrument is used, the lower end of the stem is set into an aperture in the prime conductor, and the intensity of the electric action is indicated by the number of degrees the index is repelled from the perpendicular.

The passage of the electric fluid through a perfect conductor is never attended with light, or the crackling noise, which is heard when it is transmitted through the air, or along the surface of an electric.

Several curious experiments illustrate this principle, for if fragments of tin foil, or other metal, be pasted on a piece of glass, so near each other that the electric fluid can pass between them, the whole line thus formed with the pieces of metal, will be illuminated by the passage of the electricity from one to the other

Fig. 219.



In this manner, figures or words may be formed, as in fig. 219, which by connecting one of its ends with the prime conductor, and the other with the ground, will, when the electric fluid is passed through the whole, in the dark, appear one continuous and vivid line of fire.

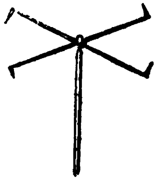
Electrical light seems not to differ, in any respect, from the light of the sun, or of a burning lamp. Dr. Wollaston observed, that when this light was seen through a prism, the ordinary colors arising from the decomposition of light were obvious.

Describe that represented at fig. 219, together with the mode of using it. When the electric fluid passes along a perfect conductor, is it attended with light and noise, or not? When it passes along an electric, or through the air, what phenomena does it exhibit? Describe the experiment, fig. 219, intended to illustrate this principle.

The brilliancy of electrical sparks is proportional to the conducting power of the bodies between which it passes. When an imperfect conductor, such as a piece of wood, is employed, the electric light appears in faint, red streams, while, if passed between two pointed metals, its color is of a more brilliant red. Its color also differs, according to the kind of substance from, or to which, it passes, or it is dependant on peculiar circumstances. Thus, if the electric fluid passes between two polished metallic surfaces, its color is nearly *white;* but if the spark is received by the finger from such a surface, it will be *violet*. The sparks are *green*, when taken by the finger from a surface of silvered leather; *yellow*, when taken from finely powdered charcoal; and *purple*, when taken from the greater number of imperfect conductors.

When the electric fluid is discharged from a point, it is always accompanied by a current of air, whether the electricity be positive or negative. The reason of this appears to be, that the instant a particle of air becomes electrified, it repels, and is repelled by the point from which it received the electricity.

Fig. 220.



Several curious little experiments are made on this principle. Thus, let two cross wires, as in fig. 220, be suspended on a pivot, each having its point bent in a contrary direction, and electrified by being placed on the prime conductor of a machine. These points, so long as the machine is in action, will give off streams of electricity, and as the particles of air repel the points by which they are electrified, the little machine will turn round rapidly, in the direction contrary to that of the stream of electricity. Perhaps, also, the reaction of the atmosphere against the current of air given off by the points, assists in giving it motion.

When one part, or side of an electric, is positively, the other part, or side, is negatively electrified. Thus, if a plate of glass be positively electrified on one side, it will be negatively elec-

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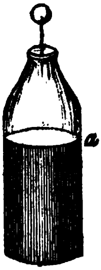
What is the appearance of electrical light through a prism? What is said concerning the different colors of electrical light, when passing between surfaces of different kinds? Describe fig. 220, and explain the principle on which its motion depends. Suppose one part, or side of an electric, is positive what will be the electrical state of the other side or part?

trified on the other, and if the inside of a glass vessel be positive, the outside will be negative.

Advantage of this circumstance is taken, in the construction of electrical jars, called, from the place where they were first made, *Leyden vials*.

Fig. 221.



The most common form of this jar is represented by fig. 221. It consists of a glass vessel, coated, on both sides, up to *a* with tin foil; the upper part being left naked, so as to prevent a spontaneous discharge, or the passage of the electric fluid from one coating to the other. A metallic rod, rising two or three inches above the jar, and terminating at the top with a brass ball, which is called the *knob* of the jar, is made to descend through the cover, till it touches the interior coating. It is along this rod that the charge of electricity is conveyed to the inner coating, while the outer coating is made to communicate with the ground.

When a chain is passed from the prime conductor of an electrical machine to this rod, the electricity is accumulated on the tin foil coating, while the glass above the tin foil prevents its escape, and thus the jar becomes charged. By connecting together a sufficient number of these jars, any quantity of the electric fluid may be accumulated. For this purpose all the interior coatings of the jars are made to communicate with each other, by metallic rods passing between them, and finally terminating in a single rod. A similar union is also established, by connecting the external coats with each other. When thus arranged, the whole series may be charged, as if they formed but one jar, and the whole series may be discharged at the same instant. Such a combination of jars is termed an *electrical battery*.

For the purpose of making a direct communication between the inner and outer coating of a single jar, or battery, by which a discharge is effected, an instrument called a *discharging* rod is employed. It consists of two bent metallic rods, terminated at one end by brass balls, and at the other end connected

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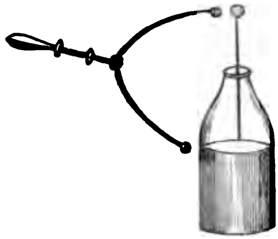
What part of the electrical apparatus is constructed on this principle? How is the Leyden vial constructed? Why is not the whole surface of the vial covered with the tin foil? How is the Leyden vial charged? In what manner may a number of these vials be charged? What is an electrical battery?

by a joint. This joint is fixed to the end of a glass handle; and the rods being moveable at the joint, the balls can be separated, or brought near each other, as occasion requires. When opened to a proper distance, one ball is made to touch the tin foil on the outside of the jar, and then the other is brought in contact with the knob of the jar, as seen in fig. 222. In this manner a discharge is effected, or an equilibrium produced between the positive and negative sides of the jar.

Fig. 222.



When it is desired to pass the charge through any substance for experiment, then an *electrical circuit* must be established, of which the substance to be experimented on, must form a part. That is, the substance must be placed between the ends of two metallic conductors, one of which communicates with the positive, and the other with the negative side of the jar, or battery.

When a person takes the electrical shock in the usual manner, he merely takes hold of the chain connected with the outside coating, and the battery being charged, touches the knob with his finger, or with a metallic rod. On making this circuit, the fluid passes through the person from the positive to the negative side.

Any number of persons may receive the electrical shock, by taking hold of each other's hands, the first person touching the knob, while the last takes hold of a chain connected with the external coating. In this manner, hundreds, or perhaps thousands of persons, will feel the shock at the same instant, there being no perceptible interval in the time when the first and the last person in the circle feels the sensation excited by the passage of the electric fluid.

The atmosphere always contains more or less electricity, which is sometimes positive, and at others negative. It is however most commonly positive, and always so when the sky

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Explain the design of fig. 222, and show how an equilibrium is produced by the discharging rod. When it is desired to pass the electrical fluid through any substance, where must it be placed in respect to the two sides of the battery? Suppose the battery is charged, what must a person do to take the shock? What circumstance is related, which shows the surprising velocity with which electricity is transmitted? Is the electricity of the atmosphere positive or negative?

is clear, or free from clouds or fogs. It is always stronger in winter than in summer, and during the day than during the night. It is also stronger at some hours of the day than at others; being strongest about 9 o'clock in the morning, and weakest about the middle of the afternoon. These different electrical states are ascertained by means of long metallic wires extending from one building to another, and connected with electrometers.

It was proved by Dr. Franklin, that the electric fluid and *lightning* are the same substance, and this identity has been confirmed by subsequent writers on the subject.

If the properties and phenomena of lightning be compared with those of electricity, it will be found that they differ only in respect to degree. Thus lightning passes in irregular lines through the air; the discharge of an electrical battery has the same appearance. Lightning strikes the highest pointed objects—takes in its course the best conductors—sets fire to non-conductors, or rends them in pieces—and destroys animal life; all of which phenomena are caused by the electric fluid.

Buildings may be secured from the effects of lightning, by fixing to them a metallic rod, which is elevated above any part of the edifice and continued to the moist ground, or to the nearest water. Copper, for this purpose, is better than iron, not only because it is less liable to rust, but because it is a better conductor of the electric fluid. The upper part of the rod should end in several fine points, which must be covered with some metal not liable to rust, such as gold, platina, or silver. *No protection is afforded by the conductor unless it is continued without interruption from the top to the bottom of the building, and it cannot be relied on as a protector, unless it reaches the moist earth, or ends in water connected with the earth.* Conductors of copper, may be three fourths of an inch in diameter, but those of iron should be at least an inch in diameter. In large buildings, complete protection requires many lightning rods, or that they should be elevated to a height above the building in proportion to the smallness of their numbers, for modern experiments have proved that a rod only pro-

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At what times does the atmosphere contain most electricity? How are the different electrical states of the atmosphere ascertained? Who first discovered that electricity and lightning are the same? What phenomena are mentioned which belong in common to electricity and lightning? How may buildings be protected from the effects of lightning? Which is the best conductor, iron or copper? What circumstances are necessary, that the rod may be relied on as a protector?

tects a circle around it, the radius of which is equal to twice its length above the building.

Some fishes have the power of giving electrical shocks, the effects of which are the same as those obtained by the friction of an electric. The best known of these are the *Torpedo*, the *Gymnotus electricus*, and the *Silurus electricus*.

The torpedo, when touched with both hands at the same time, the one hand on the under, and the other on the upper surface, will give a shock like that of the Leyden vial; which shows that the upper and under surfaces of the electric organs are in the positive and negative state, like the inner and outer surfaces of the electrical jar.

The gymnotus electricus, or electrical eel, possesses all the electrical powers of the torpedo, but in a much higher degree. When small fish are placed in the water with this animal, they are generally stunned, and sometimes killed, by his electrical shock, after which he eats them if hungry. The strongest shock of the gymnotus, will pass a short distance through the air, or across the surface of an electric, from one conductor to another, and then there can be perceived a small, but vivid spark of electrical fire: particularly if the experiment be made in the dark. *Galvanism. See Chemistry.*

MAGNETISM.

The native *Magnet*, or *Loadstone*, is an ore of iron, which is found in various parts of the world. Its color is iron black, its specific gravity from 4 to 5, and it is sometimes found in crystals. This substance without any preparation attracts iron and steel, and when suspended by a string, will turn one of its sides towards the north, and another towards the south.

It appears that an examination of the properties of this species of iron ore, led to the important discovery of the magnetic needle, and subsequently laid the foundation for the science of Magnetism, though at the present day magnets are made without this article.

The whole science of magnetism is founded on the fact that pieces of iron or steel, after being treated in a certain manner, and then suspended, will constantly turn one of their ends to-

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What animals have the power of giving electrical shocks? Is this electricity supposed to differ from that obtained by art? How must the hands be applied to take the electrical shock of these animals? What is the native magnet or loadstone? What are the properties of the loadstone? On what is the whole subject of magnetism founded?

wards the north, and consequently the other towards the south. The same property has been more recently proved to belong to the metals *nickel* and *cobalt*, though with much less intensity.

The *poles* of a magnet are those parts which possess the greatest power, or in which the magnetic virtue seems to be concentrated. One of the poles points north, and the other south. The *magnetic meridian* is a vertical circle in the heavens, which intersects the horizon at the points to which the magnetic needle, when at rest, directs itself.

The *axis* of a magnet, is a right line which passes from one of its poles to the other.

The *equator* of a magnet, is a line perpendicular to its axis, and is at the centre between the two poles.

The leading properties of the magnet are the following. It attracts iron and steel, and when suspended so as to move freely, it arranges itself so as to point north and south; this is called the *polarity* of the magnet. When the *south* pole of one magnet is presented to the *north* pole of another, they will attract each other: this is called *magnetic attraction.* But if the two north or two south poles be brought together, they will repel each other, and this is called *magnetic repulsion.* When a magnet is left to move freely, it does not lie in a horizontal direction, but one pole inclines downwards, and consequently the other is elevated above the line of the horizon. This is called the *dipping*, or *inclination* of the magnetic needle. Any magnet is capable of communicating its own properties to iron or steel, and this again will impart its magnetic virtue to another piece of steel, and so on indefinitely.

If a piece of iron or steel be brought near one of the poles of a magnet, they will attract each other, and [illegible] suffered to come into contact, will adhere so as to require force to separate them. This attraction is mutual; for the iron attracts the magnet with the same force that the magnet attracts the iron. This may be proved, by placing the iron and magnet on pieces of wood floating on water, when they will be seen to approach each other mutually.

The force of magnetic attraction varies with the distance in the same ratio as the force of gravity; the attracting force be-

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What other metals besides iron possess the magnetic property? What are the poles of a magnet? What is the axis of a magnet? What is the equator of a magnet? What is meant by the polarity of a magnet? When do two magnets attract, and when repel each other? What is understood by the dipping of the magnetic needle?

ing inversely as the square of the distance between the magnet and the iron.

The magnetic force is not sensibly affected by the interposition of any substance except those containing iron, or steel. Thus, if two magnets, or a magnet and piece of iron, attract each other with a certain force, this force will be the same, if a plate of glass, wood, or paper, be placed between them. Neither will the force be altered, by placing the two attracting bodies under water, or in the exhausted receiver of an air pump. This proves that the magnetic influence passes equally well through air, glass, wood, paper, water, and a vacuum.

Heat weakens the attractive power of the magnet, and a white heat entirely destroys it. Electricity will change the poles of the magnetic needle, and the explosion of a small quantity of gun-powder on one of the poles, will have the same effect.

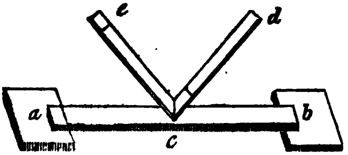
The attractive power of the magnet may be increased by permitting a piece of steel to adhere to it, and then suspending to the steel a little additional weight every day, for it will sustain, to a certain limit, a little more weight on one day, than it would on the day before.

Small natural magnets will sustain more than large ones in proportion to their weight. It is rare to find a natural magnet, weighing 20 or 30 grains, which will lift more than thirty or forty times its own weight. But a minute piece of natural magnet, worn by Sir Isaac Newton, in a ring, which weighed only three grains, is said to have been capable of lifting 746 grains, or nearly 250 times its own weight.

The magnetic property may be communicated from the loadstone, or artificial magnet, in the following manner, it being understood that the north pole of one of the magnets employed, must always be drawn towards the south pole of the new magnet, and that the south pole of the other magnet employed, is to be drawn in the contrary direction. The north poles of magnetic bars are usually marked with a line across them so as to distinguish this end from the other.

How is it proved that the iron attracts the magnet with the same force that the magnet attracts the iron? How does the force of magnetic attraction vary with the distance? Does the magnetic force vary with the interposition of any substance between the attracting bodies? What it the effect of heat on the magnet? What is the effect of electricity, or the explosion of gun-powder on it? How may the power of a magnet be increased? What is said concerning the comparative powers of great and small magnets?

Fig. 223.



Place two magnetic bars, *a* and *b*, fig. 223, so that the north end of one may be nearest the south end of the other, and at such a distance, that the ends of the steel bar to be touched, may rest upon them. Having thus arranged them, as shown in the figure. take the two magnetic bars, *d* and *e*, and apply the south end of *e*, and the north end of *d*, to the middle of the bar *c*, elevating their ends as seen in the figure. Next separate the bars *e* and *d*, by drawing them in opposite directions along the surface of *c*, still preserving the elevation of their ends; then removing the bars *d* and *e* to the distance of a foot or more from the bar *c*, bring their north and south poles into contact, and then having again placed them on the middle of *c*, draw them in contrary directions, as before. The same process must be repeated many times, on each side of the bar, *c*, when it will be found to have acquired a strong and permanent magnetism.

If a bar of iron be placed, for a long period of time, in a north and south direction. or in a perpendicular position, it will often acquire a strong magnetic power. Old tongs, pokers, and fire shovels, almost always possess more or less magnetic virtue, and the same is found to be the case with the iron window bars of ancient houses, whenever they have happened to be placed in the direction of the magnetic line.

A *magnetic needle*, such as is employed in the mariner's and surveyor's compass, may be made by fixing a piece of steel on a board, and then drawing two magnets from the centre towards each end, as directed, at fig. 223. Some magnetic needles in time lose their virtue, and require again to be magnetized. This may be done by placing the needle, still suspended on its pivot, between the opposite poles of two magnetic bars. While it is receiving the magnetism, it will be agitated, moving backwards and forwards, as though it were animated, but when it has become perfectly magnetized, it will remain quiescent.

Explain fig. 223, and describe the mode of making a magnet. In what positions do bars of iron become magnetic spontaneously? How may a needle be magnetized without removing it from its pivot?

The *dip*, or *inclination* of the magnetic needle, is its deviation from its horizontal position, as already mentioned. A piece of steel, or a needle, which will rest on its centre, in a direction parallel to the horizon, before it is magnetized, will afterwards incline one of its ends towards the earth. This property of the magnetic needle was discovered by a compass maker, who, having finished his needles before they were magnetized, found that immediately afterwards, their north ends inclined towards the earth, so that he was obliged to add small weights to their south poles, in order to make them balance, as before.

The dip of the magnetic needle is measured by a graduated circle, placed in the vertical position, with the needle suspended by its side. Its inclination from a horizontal line marked across the face of this circle, is the measure of its dip. The circle, as usual, is divided into 360 degrees, and these into minutes and seconds.

The dip of the needle does not vary materially at the same place, but differs in different latitudes, increasing as it is carried towards the north, and diminishing as it is carried towards the south. At London, the dip for many years has varied little from 72 degrees. In the latitude of 80 degrees north, the dip, according to the observations of Capt. Parry, was 88 degrees.

Although, in general terms, the magnetic needle is said to point north and south, yet this is very seldom strictly true, there being a variation in its direction, which differs in degree at different times and places. This is called the *variation*, or *declination*, of the magnetic needle.

This variation is determined at sea, by observing the different points of the compass at which the sun rises, or sets, and comparing them with the true points of the sun's rising or setting according to astronomical tables. By such observations, it has been ascertained, that the magnetic needle is continually declining alternately to the east, or west, from due north, and that this variation differs in different parts of the world at the same time, and at the same place at different times.

How was the dip of the magnetic needle first discovered? In what manner is the dip measured? What circumstance increases or diminishes the dip of the needle? What is meant by the declination of the magnetic needle? How is this variation determined? What has been ascertained, concerning the variation of the needle at different times and places?